Towards best practice collision analysis for Vision Zero Programs

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ABSTRACT

Many cities in the United States want to drastically reduce transportation-related deaths by implementing "Vision Zero" programs and policies. Given the financially-constrained circumstances in American cities, many are turning to collision data analysis to prioritize and justify safety investments and roadway design changes. However, differences in methodology –such as geographic areas used – can lead to different results. Cities with Vision Zero policies in place have thoughtfully considered this issue in their approaches through protracted research and studies; however, not all cities have the resources for such an intensive project. We attempt to provide direction for public officials who wish to implement a Vision Zero policy by distilling common themes from peer-reviewed literature on bicycle and pedestrian crash determinants; examining current Vision Zero policies adopted in the United States; a Vision Zero implementation plan assignment from a graduate urban planning course; and our own analysis using collision data from Los Angeles, California. We then synthesize the prior work and our own analysis to recommend a number of factors cities should consider before and during their collision analysis process for use in Vision Zero policies and programs; highlighting the importance of bicycle and pedestrian data collection, recommending roadway corridors as the geographical units of analysis, and strongly emphasizing transparency in the development of a methodology.

INTRODUCTION AND PURPOSE

Fatalities from motor vehicle collisions are the leading cause of death for people under the age of 45 in the United States (1). Each of these tragedies is preventable. Indeed, due to a combination of seatbelt use, drunk driving enforcement, education, and other strategies, the number of vehicle occupant deaths has considerably declined over the last ten years. Yet, the number of deaths for people walking or riding a bicycle has *increased* over the same time period (2). These differing trends suggest that while some roadway safety programs may be helping vehicle roadway safety, there is a need for increased attention to the safety of more vulnerable roadway users. Two types of programs are emerging in response to both highway safety and street safety in cities; Toward Zero Death efforts in Highway and State Department of Transportations and Vision Zero programs in cities.

This paper focuses on municipal efforts within Vision Zero programs and we do not include references to state level Towards Zero Death efforts. Our work is a direct response to a call from the Major Cities committee for the Transportation Research Board, which guides its municipal focus. City transportation issues are more complex and different in nature than highway transportation issues. Most highways are limited access and do not need to plan for people who are not traveling in vehicles. Cities do not have this luxury. City streets are a cacophony of cars, public transit vehicles, and people on bicycles, people walking; with a lot of mixing in the street space. And most cities must plan for population growth; likely meaning more mixing in the future. Many cities are planning for more transit service, a litany of bicycle infrastructure improvements and pedestrian safety efforts.

These efforts are borne from existing safety issues, in addition to population growth. Sadly, the number of collisions where people walking and cycling are involved is increasing at the same time that every level of government is investing more funding into bicycle and pedestrian related projects. Since 1991, the federal government made more funding available for bicycle, pedestrian and transit-related projects than the past 30 years combined (3). This includes funding from federal surface transportation bills— ISTEA, SAFETEA-LU and MAP-21 — and billions of dollars from the Transportation Investment Generating Economic Recovery (TIGER) discretionary grant program. Even private companies are throwing their dollars into the ring with capital investment dollars in bikeshare systems. Why then, if there is more money going towards biking and walking, are more people dying when they are walking and riding bicycles?

The answer to this question is likely a story partly about the volumes of people walking and people biking — in either very high or very low numbers — and partly about street design that encourage fast cars to dangerously mix with people walking and riding bicycles. In this paper, we chose to focus on bicyclist and pedestrian involved crashes for a number of reasons. People traveling by these modes are the most physically vulnerable since they travel without the protections in cars such as seat belts and other vehicle safety features. We offer an equity lens to this analysis by solely focusing on these modes; many researchers, as summarized in Schweitzer and Valenzuela (2004) (4), find the poor and those living in minority neighborhoods are more affected by collisions and other environmental externalities of transportation. Lastly, we limit our analysis because of simplicity; if we focus on collisions involving all modes of travel, we have a larger universe of factors to consider and we want to provide more specific findings and recommendations.

Therefore, this paper examines the trends for safety programs with a focus on bicyclists and pedestrians occurring in American cities, many of which are experiencing population growth and the subsequent increased demand for travel by all modes. Because transportation-related deaths are largely acknowledged as preventable, many cities are now making commitments to increase safety with the goal of having zero roadway deaths each year by adopting so-called Vision Zero (VZ) policies.

This approach has proven successful in Sweden as they now have the world's lowest traffic fatality rates and pedestrian-related deaths have fallen by almost 50% in the last five years alone (5). On the heels of the Swedish approach and related efforts in other countries such a Sustainable Safety in the Netherlands, the European Union (EU) set a goal to halve road deaths between 2001 and 2010; in 2010 the commitment was renewed and the EU set further road safety targets (6). Pedestrian deaths have decreased in all EU countries after implementing the Vision Zero strategy. The European examples provide context for dealing with safety initiatives at the local, regional and national levels. In sum; the efforts from a variety of different geographic levels demonstrate the ability to reduce these dangerous collision trends.

The success of these programs lies in their details and specific approach. Targeted roadway safety programs, Vision Zero, Sustainable Safety, Toward Zero Death among others, include many key elements: enforcement of safety regulations, education for all road users, speed limit reductions, and physical roadway design changes. Typically, infrastructure and operational changes are targeted toward areas determined to have the worst collision history via a data-driven analysis. Analyzing crash patterns may appear to be a straight-forward task; but in fact, there is room for discrete choices to be made that may affect the analysis and resulting priority areas. Since priority areas usually receive more expedient funding for improvements, those choices are not inconsequential.

The intent of this paper is to assist cities or other groups analyzing historic collision data in order to prioritize Vision Zero improvements in municipalities. We borrow some lessons from state transportation Towards Zero Death efforts but those are tangential to the focus of our work. We seek to bridge the gap between peer-reviewed research and practice through analyzing prior work and Vision Zero programs to date.

The paper is organized as follows. First, we review and summarize existing research about determinants of bicycle, pedestrian, and motor vehicle collisions. Next, we highlight the collision data analysis methodologies from the eight existing VZ programs in the United States. This is followed by original analysis in two forms: summarizing a graduate-level classroom experiment where 30 students were asked to provide recommendations for a hypothetical Los Angeles VZ program and our own analysis which builds on the peer-reviewed literature and municipal approaches. We draw on all four components as we discuss the implications of collision data analysis. The end of this paper provides recommendations for future collision analysis; pointing out the near-universal absence of bicycle and pedestrian volume data in all of the previous analyses. The overarching goal of this paper is to provide key questions and recommendations for cities to think about when conducting spatial collision analysis for Vision Zero programs or other safety programs.

LITERATURE REVIEW

Peer-Reviewed Approaches

Numerous researchers from urban planning, transportation planning and engineering, and public health disciplines have analyzed collision patterns to better understand what factors may be related to high crash areas. Most studies model how characteristics about the collision, the street and the built environment (namely land use) in a given area affect the frequency or severity of collisions. The different types of study aims can be categorized broadly into three themes: research to understand how the built environment and/or socio-economic status indicators effects bicycle/pedestrian crash severity and likelihood; personal risk factors as determinants of crash severity; or researchers who were more concerned about developing appropriate methodologies for the statistical analysis and prediction of accident clustering. Table 1 below summarizes a number of studies for categories 1 and 2 as they are most relevant to VZ collision analysis.

TABLE 1 Summary of Prior Work

Paper and Geography	**Modeling inputs**	**Modeling approach**	**Unit of analysis**	**Significant factors**
Aziz 2012 (7) New York City	Pavement and road characteristics, traffic characteristics, crash related factors, land use and demographics	Random parameter multinomial logit	Intersection	Differs for each borough; road characteristics, roadway design and land use are pervasive
Clifton 2009 (8) Baltimore	Collision characteristics, land use mix, intersection density / ped. Connectivity, transit availability, SES factors, road facility type	Ordered probit model	¼ mile buffer from each collision	Personal and behavioral characteristics, transit access and pedestrian connectivity
Clifton and Kramer-Fults 2007 (9) Baltimore	Collision characteristics, school type, roadway type, SES factors, population density, transit access, land use	OLS linear regression	¼ mile buffer from schools	Race, recreational opportunities at schools, driveway presence
Dai 2012 (10) Atlanta region	Collision characteristics, person behavior lighting and surface conditions	OLS regression	Identified collision clusters	Children, seniors and influence of alcohol, high-activity suburban corridors,
Dumbaugh (11) San Antonio region	VMT, block group size, intersection density, freeway and arterial mileage, commercial land use, big box stores, pedestrian scale land use	Binomial regression	Census tract	Miles of arterial roadway, four-leg intersections, strip commercial uses and big box stores

TABLE 1 (Continued)

Paper and Geography	Modeling inputs	Modeling approach	Unit of analysis	Significant factors
Graham and Glasister 2003 (12) England	Population density, traffic volume, SES factors, land use	Negative binomial model	Wards	Population and employment density, and some land uses
Lee and Abdel-Aty 2005 (13) Florida	Collision characteristics, driver characteristics, vehicle characteristics, traffic control type, number of lanes, lighting, weather and urban vs. rural	Log-linear model & ordered probit model	Intersect ions	Middle aged male drivers and pedestrians, driver speed, higher traffic volume
Loukaitou Sideris, Liggett and Song 2007 (14) Los Angeles	Population and employment density, AADT, SES/demographics, and land use	OLS regression	Census tract	All input except non-commercial and high density residential land uses
Mitra and Buling 2012 (15) Toronto	SES factors, collision factors, block density, intersection density, lighting, all roads, major roads	Binomial logistic regression	Various unit sizes	Does not modeling collisions; models the percentage of school aged children using active transportation
Siddiqui 2012 (16) Florida	Parking costs, household car ownership, SES factors, speed limits and intersection density	Bayesian Poisson-lognormal model	Traffic analysis zones	Higher speed limits and intersection density.
Wier et. Al, 2009 (17) San Francisco	Traffic volume, intersections, street length by type, SES factors, commute modal information	Multivariate regression	Census tract	Traffic volume, arterial streets without public transit, commercial land uses, seniors and proportion of people living in poverty

All the studies referenced in Table 1 focus on one metropolitan area at a time; therefore, it's difficult to say whether the findings from these individual analyses are applicable to other geographic regions. Some research has, in fact, pointed out that the individual contribution of different variables may vary by geographic region. Aziz et al. models for each borough in New York City to predict the severity of pedestrian-vehicle crashes. Each model yielded different sets of statistically significant determinants, suggesting that the differences in urban form across the boroughs have varying effects on pedestrian-vehicle crash rate and severity (7). The last column in the table demonstrates that many factors contribute to the likelihood and severity of bicycle and pedestrian involved collisions. The most common factors are arterial roadways (presence or total miles), commercial land use and speed limits/driver speed. Loukaitou-Sideris et al. (14)argue that the socio-economic status of neighborhoods may also have an effect. They suggest residents in these low-income high density urban neighborhoods are unduly burdened by higher rates of fatal or severe collisions.

Table 1 also highlights the differing geographies used in each analysis. Conducting spatial analysis using a geographic area as the primary unit of analysis lends itself to the modifiable areal unit problem (MAUP). The MAUP posits that, given a wide enough area, the descriptive variables of that area will average out; the size of a geographic unit can meaningfully affect the results of spatial analyses. Mitra and Buliung (15) estimated the determinants of active transportation for school children in Toronto at six different spatial units with a binomial logistic regression. Coefficients for the statistically significant variables were different across each spatial unit, suggesting the presence of a MAUP.

City-Based Approaches

We analyzed Vision Zero analysis methodologies for the seven existing US Vision Zero programs.

As of July 2015, we found documentation for the following U.S based Vision Zero programs:

- Boston, MA
- New York City, NY
- San Diego, CA
- San Francisco, CA
- San Jose, CA
- Seattle, WA
- Washington D.C

More cities are now considering Vision Zero and are at various stages of program development. This includes Fremont, San Mateo, Long Beach Los Angeles and Santa Ana (all in California); Denver, CO; Austin, TX; Chicago, IL; Pittsburgh and Philadelphia, Pennsylvania.

We surveyed two primary sources for this analysis: public documents regarding Vision Zero programs including presentations, reports and websites; and cyclist and pedestrian safety reports published by the city in focus. We do not assume that the methodologies in the safety reports will be the adopted methodologies for Vision Zero prioritization, but these previous studies provide clues as to how the agency is likely to approach the analysis for this program; Vision Zero is a safety program so reviewing bicycle and pedestrian safety repots has a nexus to VZ programs. Table 2 summarizes our findings. We highlighted the programs and their date of inception, noting the rapid pace of adoption — six of the seven have emerged in the past six months. We looked to see the type of geography they are prioritizing; areas, streets or intersections, and the dataset used in the analysis. We found almost all of the cases to have some reference to priority areas. However, these are less often well-defined in the Vision Zero reports themselves, hence why we also included the safety and other relevant reports in the last column.

TABLE 2: Summary of Adopted Vision Zero Policies in the United States

City and launch date	Data set	Priority unit	Vision Zero Analysis approach	Previous collision analysis approaches
Boston, MA March 2015	Fatal and serious injury bicycle and pedestrian collisions.	None published to date.	Analyzing hot spots in coordination with police department.	Bike safety report (18) highlighted intersections and street corridor segments with high collision frequency.
New York City, NY January 2014	5 years of fatal and serious injury bicycle and pedestrian collisions.	Borough (Manhattan) then area, intersections and corridors within Manhattan. (19)	Measure KSI incidents per mile on all street corridor segments.	Top corridors were selected in each borough until the cumulative number was 50% of all KSI collisions (20). Top corridors represent top 15% of all.
San Diego, CA June 2015	All bicycle and pedestrian collisions; pedestrian safety used five years of data (21).	Street corridor segments (recommendation from partner advocacy organization).	No official city approach to date.	Pedestrian analysis looked at collisions per mile by census block group and tract (22); summarized by employment density, population density and median income. Collision analysis in bicycle master plan used 5 years of data but provided no geographic specific recommendations (23).
Portland, OR June 2015	Collision website includes all severities and all historic data (2004 - 2013).	High crash corridors (24).	Top 10 arterial roadway segments representing 50% of pedestrian fatalities (25).	Pedestrian research (26) report divides high collision corridors by city quadrants (i.e. NE, SW, etc.). High collision locations use 4 years of data and measure collision rate = Total collisions / (ADT x 340days x 4years / 1,000,000veh's).
San Francisco, CA February 2014	5 years of severe fatal injury collision data (27) - KSI per 100 road miles per district.	Corridors and some intersections outside of priority corridors within 2 priority supervisorial (council district) areas (28).		Identified corridors with high actual or potential volumes of pedestrians and overlaid with high frequency and severity of collisions (29).

City and launch date	Data set	Priority unit	Vision Zero Analysis approach	Previous collision analysis approaches
San Jose, CA April 2015	1 year of most (30) recent data (2014) with fatalities and severe injuries for all modes; but maybe 5 years of data (2009 - 2014).	Street corridor segments	Selected top 14 segments until cumulatively 50% of KSI events were accounted for.	Priority areas and most methodology included in Vision Zero report
Seattle, WA February 2015	Charts examine collisions from 2004 – 2013 focusing on fatal and serious injury and collisions involving pedestrians, cyclists and motorcycles.	Arterial streets corridor segments where the speed limit is greater than 30 MPH, downtown area and “local streets with high collision history” for 20 MPH residential zones (31).	Selected corridors based mostly on existing features like higher speed limits.	
Washington D.C March 2015			“Heat map” with no legend (32)	5 years of data analyzed for all fatalities and serious injury collisions; (33) separate analysis by mode. But no geographies or units (intersections, streets, etc.) mentioned.

TABLE 2 (Continued)

Most cities are using 5-years of collision data. Also, most case study cities/agencies, but not all analyze collisions only involving people walking and people riding bicycles. San Jose, CA and the Washington State analyses examined collisions for all modes. The motivations for selecting all collision types are unclear; but it stands to reason that this approach may make Vision Zero more broadly appealing. Most cases prioritize street corridor segments and some also include at least one focused priority area. The New York and Seattle cases both do this for the most dense commercial downtown areas; Downtown Seattle and Manhattan, respectively. The analysis in these case studies is simpler in its approach to collision analysis as compared to the peer reviewed studies. Interestingly, both approaches identify similar factors —arterial streets (a proxy for high traffic volumes and speed) and downtowns (a proxy for commercial land use) — as areas with high collision incidents and thus worthy of targeted improvements.

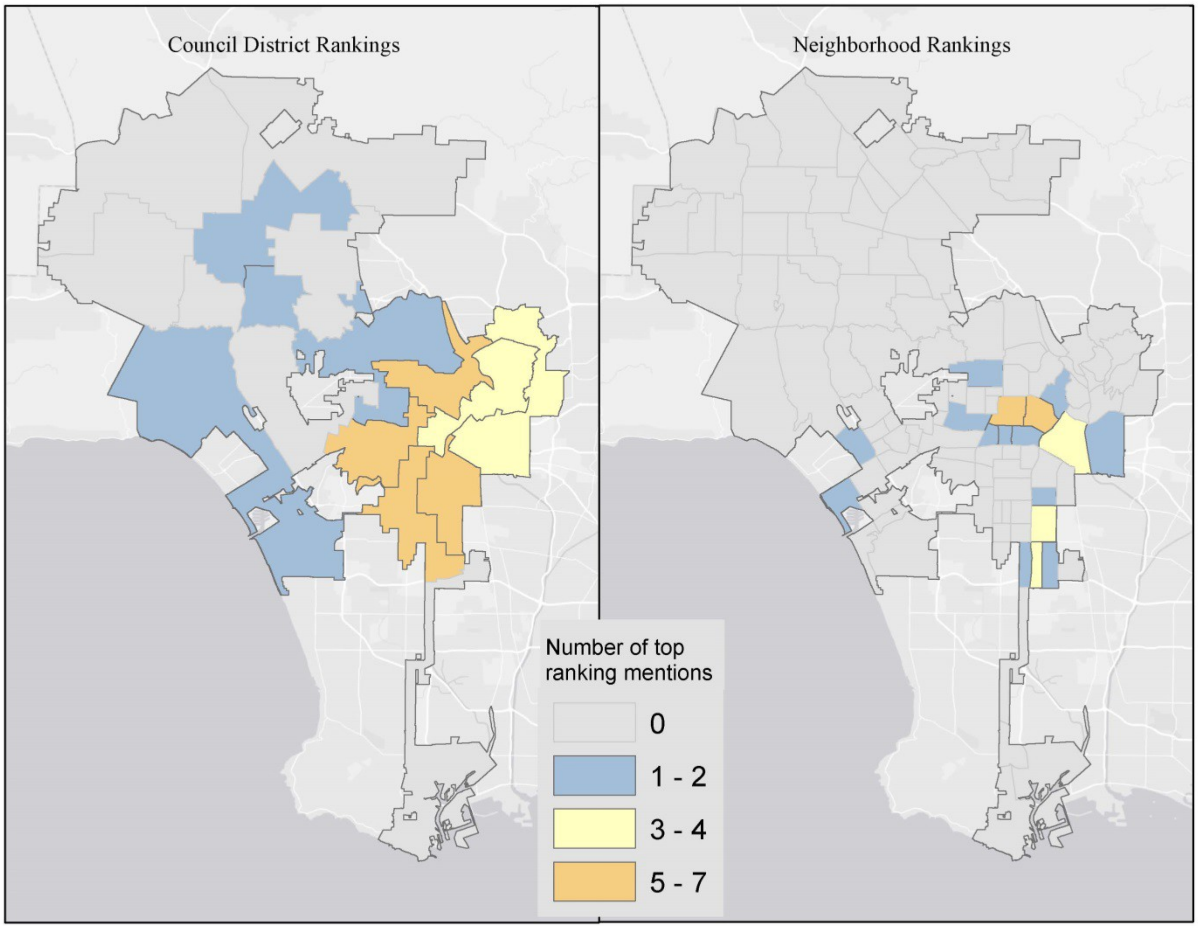
ANALYSIS

Classroom-Based Experiment

Many peer-reviewed papers included in this paper created different models to understand how differences in analysis may lead to different findings. But this approach was not explicitly included in the municipal approaches. We wanted to understand whether more simple analysis of collision data, as seen in the VZ programs, may create different outcomes depending on the methodology undertaken. Students in a spatial analysis course in a public affairs school were tasked to create an implementation plan for a Los Angeles Vision Zero program. Each student was provided the same geocoded traffic collision data from UC Berkeley's Transportation Injury Mapping System (TIMS). Using whichever methodology they prefer, students were asked to create a list of the top five areas in Los Angeles to prioritize for Vision Zero funding. The assignment yielded 31 papers, each with slightly varying methodologies; with one exception.

The results lie somewhere between the peer reviewed analyses and municipal approaches. Most students summarized the collisions by some went somewhat further. The papers used some spatial statistic approach to quantify whether the spatial patterns had any statistical significance; an approach largely absent from municipal analyses. Many papers selected similar geographies as the unit of analysis. The two most common were Los Angeles City Council District (8 papers) and neighborhood (9 papers). We took the top ranked district in each of these and mapped them by frequency of mentions below in Figure 1.
These two units of analysis are recommended for spatial investigation at the municipal level for two reasons. They are large enough to see more broad based patterns and secondly, they are a similar size within each unit. This is in contrast to census tracts, which are commonly used in the papers referenced in Table 1. Census tracts can vary largely in size because they are adjusted for population, attempting to represent approximately 4,000 people. The large council districts may show large regional trends but may hide small area variation; while census tracts may lead to the opposite result. Conversely, when the students divided the city by neighborhood, it appears that regional patterns are evident but it appears to also capture smaller micro-scale patterns as well.

Figure 1 Map of Recommended Geographies



Students conducted spatial statistical tests to see whether there was any significant clustering to the data. Two students used the Average Nearest Neighbor Distance tool to check for statistically significant clustering within each district; two papers identified specific locations with statistically significant clustering taking into account geographic location (Local Moran's I) and geographic location with injury severity (Getis-Ord Gi*); one paper developed an Ordinary Least Squares (OLS) regression to estimate the determinants of a bicycle/pedestrian collision using spatial data; and three did not deploy a statistical test for spatial clustering. None of these tests were found in the municipal reviews (Table 2) but these types of more robust analysis methods are used in the peer-reviewed studies (Table 1).

In the aggregate, most of the papers tended to recommend improvements in the central and southern portions of the city. Most interesting, though, are the differences for the total number of mentions. In the case of Council Districts, papers tended to recommend improvements in South LA, while in terms of neighborhoods, the distribution of recommended improvement areas shifted closer to downtown. This case study of papers from a school assignment helps to shed light on the challenge facing city officials who wish to enact an evidence-based implementation plan for Vision Zero policies. Changes in methodology – from geography to statistical tests – may lead to differing outputs, even if the data on which that analysis is based are the same.

Los Angeles Data

Lastly, we wanted to add our own data analysis from within the City of Los Angeles as a case-study which build upon the findings of the peer-reviewed literature, the current approaches to Vision Zero cities are taking, and our thought-process demonstrated in the classroom experiment. We provide this analysis as a strategy for cities considering Vision Zero to review and help guide the spatial analysis of historic collision data.

The data used in this case study comes from the California Statewide Inventory of Transportation Records System (SWITRS) and was accessed through the UC Berkeley Transportation Injury Mapping System (TIMS). We extracted collisions that happened within the City of Los Angeles during last 5 current years of data, from 2009-2013 (n=22,064). Each point contains information about the severity of the collision; fatal, severe injury, moderate injury and minor injury/complaint of pain.

Descriptive Statistics

The number of collisions per year in the City of Los Angeles has remained fairly stable across the five year period. There are approximately 4,400 collisions, on average, involving a person walking or person riding a bicycle in the City of Los Angeles per year. Of these collisions, 11% resulted in a fatality or serious injury. While the collisions, overall, are fairly evenly split between people walking and people riding a bike (55% pedestrian and 45% cyclist), collisions that result in a fatality or serious injury (KSI) are 3 more times likely to involve a pedestrian rather than a cyclist. Nearly 70% of all collisions happen on arterial streets. Arterial streets compose only 16% of the total center-line miles of all streets within the City of Los Angeles. The collisions resulting in a fatality or serious injury also disproportionality occur on arterial streets; 67% of all of KSI collisions happen on arterial streets.

Geographic considerations

We sought to understand how these collisions are distributed across space within the city. We used three different area measurements for this geographic analysis: census tracts, neighborhoods and council districts. The three units are different in size and number.

Census Tracts Los Angeles has 984 census tracts. Census tracts vary greatly by size because the U.S Census Bureau attempts to keep the population within each census tract equal at approximately 4,000 people. The population per census tract in LA ranges from 0 people (e.g. Los Angeles International Airport or large regional parks) to 11,298 (UCLA campus). The population per tract is normally distributed around the mean of 3,845.

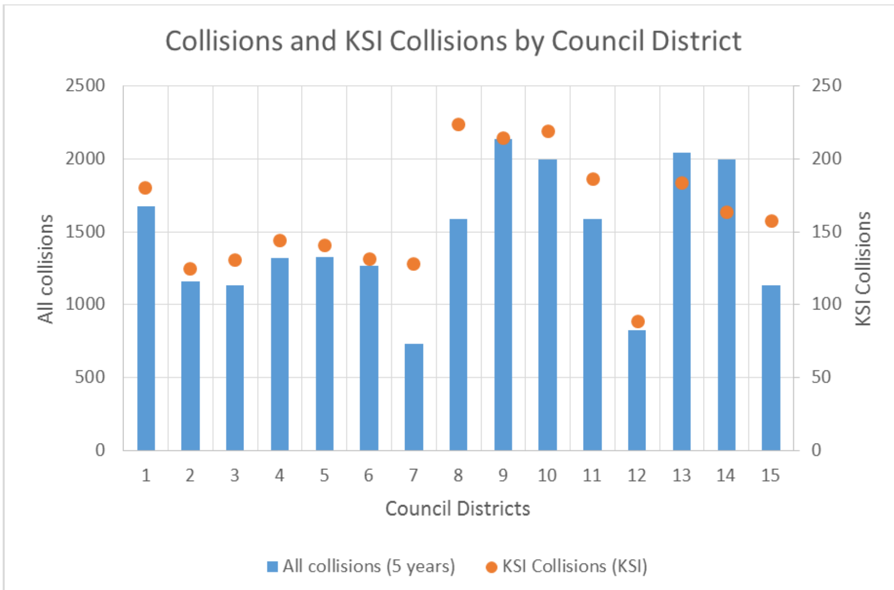
Neighborhoods In 2009, the Los Angeles Times began an effort to map and refine neighborhood boundaries in LA. They began with 87 neighborhoods through city designation (although the City has never drawn official neighborhood boundaries) and census tract boundaries; then solicited public input. This study uses the current version of this dataset with 114 neighborhoods. Using proportionally allocated population data from the U.S Census block groups, we measured the population per neighborhood. Population by neighborhood ranges from 8,184 in the small, 0.6 square mile, Rancho Park neighborhood to 127,111 people in the densely populated 2.7 sq. mile Koreatown neighborhood.

Council Districts There are fifteen council districts (CD) in Los Angeles. Similarly to the neighborhoods, we proportionally allocated population data from census block groups. Each council district has 326,844 people on average and ranges from 252,083 to 400,118 inhabitants. Council district boundaries, along with the municipal border of Los Angeles itself, are notoriously irregular. Thus, their urban characteristics may be wildly different from one another, and often times, between areas within a single district.

Geographic Comparison

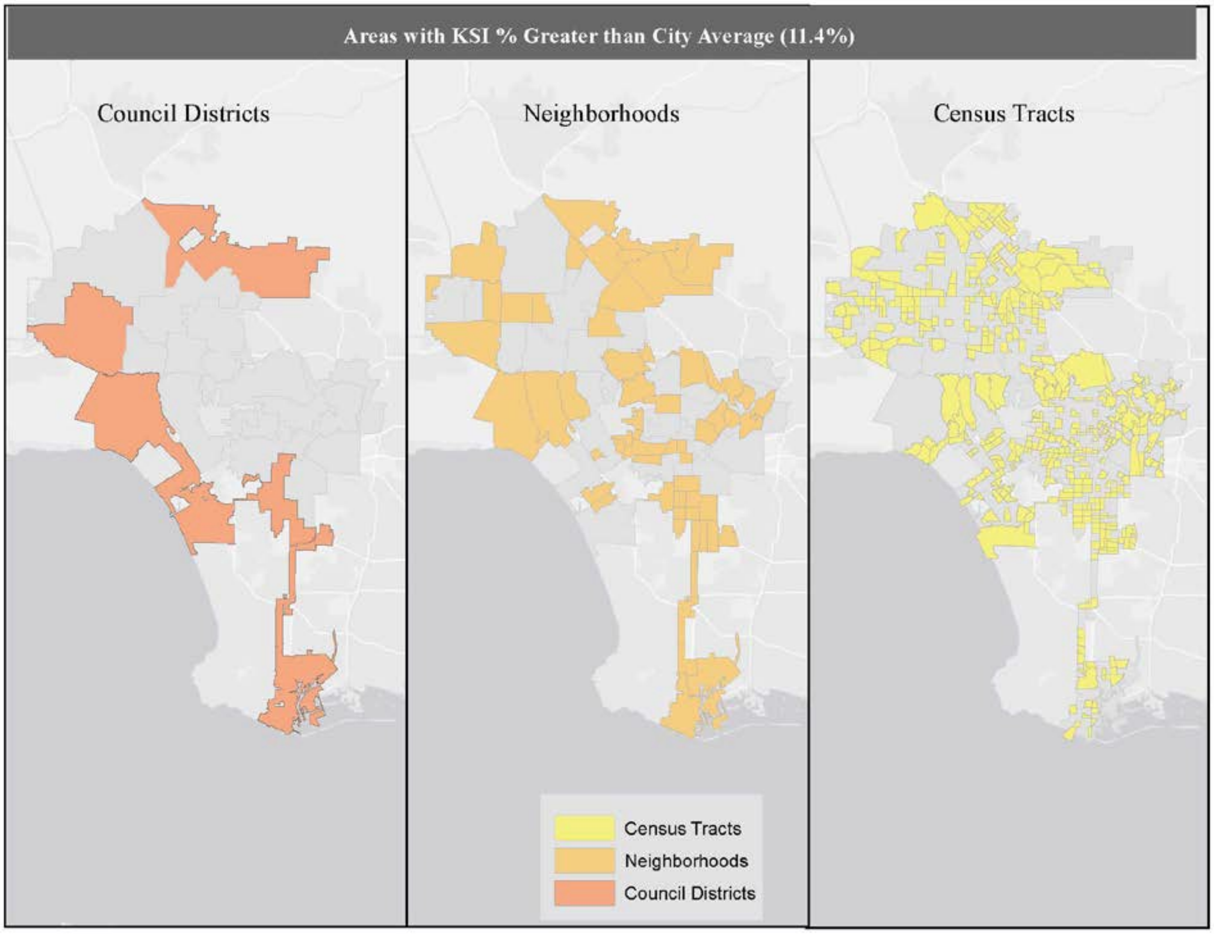
One or more KSI collision occurred in 93% of census tracts, 113 of 114 neighborhoods and all council districts. But the number of collisions and KSI collisions in each of these geographies do not happen at an equal frequency. As seen in Figure 2 below, the number of collisions per district varies from 729 (CD7) to 2,141 (CD9). The relationship between the number of collisions and number of KSI collisions also vary by council district. As previously mentioned, 11% of collisions resulted in a fatality or severe injury. On Figure 2, this would mean that the orange dots are just slightly above the blue bar (exact same placement represents 10%).

FIGURE 2 Collisions and KSI Collisions by Council District



For Council Districts 7, 8, 11 and 15, the greater distance between the blue bar and the orange dot represents a higher proportion of KSI collisions than the average in those areas. We wanted to compare if similar or different areas would appear in terms of their KSI percentage if we looked at council districts, neighborhoods or census tracts. The results are below in Figure 3.

FIGURE 3 Areas with KSI % Greater than City Average (11.4%)



We found that the smaller the unit, the more locations appeared as areas of concern where the KSI percentage was higher than the city average. This analysis demonstrates that larger area measures may hide detailed hotspots, supporting the findings in the literature of a modifiable areal unit problem (MAUP).

Lastly, we compared rates of collisions geographically. The volumes of people walking and bicycling throughout the city are the ideal dominator for a collision rate. This would help to understand exposure and risk. However, City of Los Angeles does not collect these figures. While regional advocacy organizations have collected some data about this, they are limited to only a small handful of intersections in the city. We display the KSI collisions by standard deviation showing how different areas vary from the by neighborhood in 4 ways: without normalization, by square mile, by the total miles of arterial street and by 1,000 people. The analysis is below in Figure 4. In absolute terms, the worst areas are in Downtown Los Angeles, Griffith Park and a small neighborhood in West Los Angeles, which is the only area that appears in the top ranking across all four data frames. Each normalization explains something different about the data; places like Griffith Park appear because very few people live there, but they have a large daytime population. Overall, the process of normalizing the collision data in different ways and comparing the results is a telling exercise.

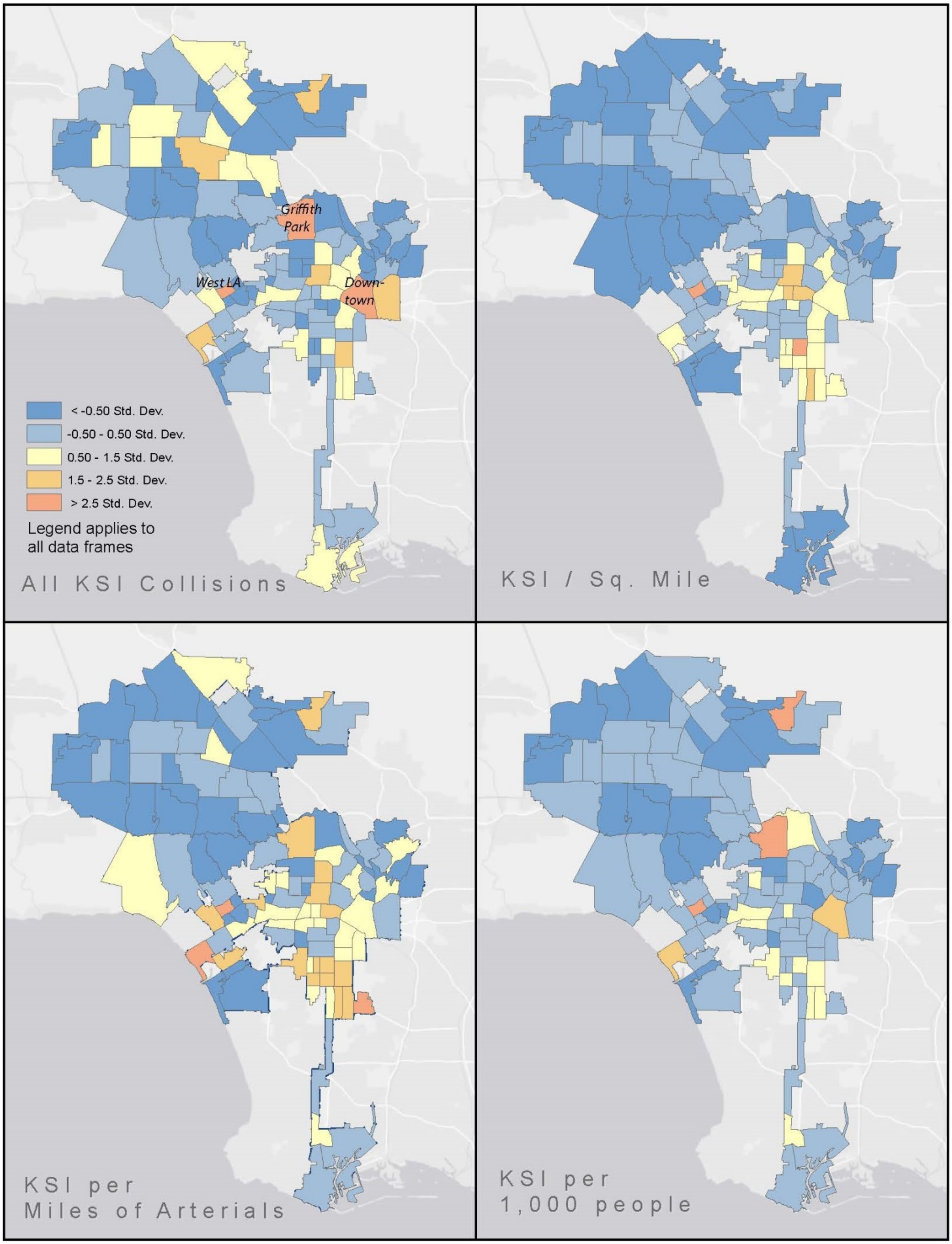


FIGURE 4 Rates of Collision with Different Normalizations

DISCUSSION

This paper highlights a number of different ways cities, advocacy organizations and other groups can analyze collision data for Vision Zero or other targeted roadway safety programs. The successful programs in Europe, including Vision Zero in Sweden and Sustainable Safety in the Netherlands, demonstrate that these types of programs have the potential to decrease roadway fatalities. Most times when a person is severely injured or dies in a traffic collision, this death or injury was avoidable. We, therefore, laud the rapid adoption of programs that focus on decreasing roadway fatalities in the United States. Unfortunately, cities are financially and resource constrained places where they cannot frankly afford to do sweeping safety improvements across every problem area. Therefore, some areas must be prioritized over others. We want to highlight the inherent difficulties in accomplishing this relatively straight-forward task for a few different reasons. First, the literature is somewhat limited spatially. And we did not find a peer-reviewed article which compared collision patterns from different cities or regions to each other, i.e. to try and understand what factors would be persistent in collisions if a few different geographical regions were compared and controlled for. Most of the studies presented in Table 1 look only look at one particular city or region. Further, many of the geographies listed in the literature review table (Table 1) are not repeated in the list of city's that currently have Vision Zero programs, as listed in Table 2. We think it may be difficult for cities to want to adopt the methods from another city because their own city context may be different from other places. For example, Boston has adopted their Vision Zero policy but there is no academic study from Boston. Nor is there a study which explains collision patterns from multiple cities that may look somewhat like Boston. This lack of comparison between different cities or states appears to be a gap in the currently existing literature.

Further, this paper does not go into collision patterns for different sub-groups like children, communities of concern for environmental justice reasons or the elderly. Our literature review finds a number of these socio-demographic factors are associated with high-collision areas. Many cities have sub-goals within the Vision Zero programs about these groups such as increasing safety near schools. While we did not explore these factors in our own analysis, we think it is prudent that spatial analysis for Vision Zero programs attempt to look into these socio-demographic issues.

Across nearly all of the work analyzed in this paper, we find the Modifiable Areal Unit Problem (MAUP). The size of a geographic unit is likely meaningfully affecting the spatial analysis results. Large geographies may highlight factors that are not relevant to the entire area, but small geographies such as census tracts may highlight a very tiny area as having a high number of collisions and find the adjacent tract to be of no consequence. In other words, are we finding real patterns in the data, or are we finding artifacts caused by where the geographic boundaries are drawn? We did find that cities attempted to skirt this issue by selecting street corridors over area measures. However, analyzing collisions at the corridor level does not do away with the issue all together. Collisions may occur on some parts of particular corridors but other portions of the street may not be as dangerous. Because the MAUP persists, cities should be careful with their analysis and attempt to balance both corridor measures and area measures.

We attempted to demonstrate how different spatial patterns emerge when you treat the data differently and highlight the importance of meaningful data normalization (Figure 4). The top left map shows areas of collision numbers alone. The top right normalizes the neighborhoods by square mile to try and see general exposure to collisions in these neighborhoods. Already these two maps look different from each other. The bottom left shows KSI collisions by miles of arterial streets because our earlier analysis showed KSI collisions occur disproportionally on arterials. In this third map, a new neighborhood appears as the highest/worst ranking that wasn't present on either of the maps at the top. The bottom right map in Figure 4 where we normalizing the data by population is somewhat problematic because some areas of the city have extremely low population. These are mostly neighborhoods with large regional parks so these outliers skewed the analysis. All of these four maps are different. A slightly different set of neighborhoods appear as the highest neighborhoods of concern where people are being killed or severely injured, in these cases while walking or riding a bicycle. Because cities are using spatial analysis to prioritize some areas over others, we urge caution throughout the analysis. We hope this exercise brings the issue of normalization, in addition to unit of analysis selection, to light as a major concern for cities before embarking on their Vision Zero collision analyses.

Recommendations

In conclusion, we offer a number of recommendations for cities and groups to consider when analyzing collision data and/or selecting priority areas for Vision Zero programs.

1. Collect more bicycle and pedestrian volumes. Nearly all of the peer-reviewed and city examples were absent of these data, the lack of which inhibits calculating a collision exposure rate. Collecting more bicycle and pedestrian volume data would help cities and researchers better understand determinants of collisions. We found that normalizing by other factors which are a proxy for these volumes can affect the rankings of different areas.
2. Focus collision analysis on arterial streets. Higher speed limits and traffic volumes were both common significant factors for collisions within the peer reviewed literature. Higher speed limits and traffic volumes are commonly present on arterial streets, the focus of many of the Vision Zero priority areas. Experience from research and practice suggest focusing on arterial streets can lead to lower instances of fatal and severe injury collisions.
3. Examine collision patterns by sub-groups in addition to overall patterns throughout the city. The peer-reviewed literature points to a relationship between socio-demographic variables and high incidents of collisions. Therefore, we think cities should look at the cities cited in Table 1 when thinking about sub-group analysis.
4. Select area unit of analysis and conduct separate analyses at the corridor level. These may create slightly different patterns which may be telling to the issues at hand.
5. Define simply and transparently how Vision Zero priority areas were selected. This may seem like a fairly evident recommendation. However, we found it time-consuming and difficult to understand how priority areas in various cities were selected. If Vision Zero programs strive to be data-driven, then the reasons behind the priority areas should be easy to pinpoint for government officials, other cities and the public at large.

If the Swedish and European experience can be thoughtfully brought to American cities and regions, this is a major opportunity for reducing the number of tragic, preventable deaths on roadways across the country.

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