RESEARCH ARTICLES

Evidence on Why Bike-Friendly Cities Are Safer for All Road Users

Wesley E. Marshall, Norman W. Garrick

Biking is increasingly being recognized as a highly sustainable form of transportation. Consequently, a growing number of American cities have seen tremendous growth in bicycle travel, in part because many cities are also investing resources into improving bicycling infrastructure. Aside from the environmental advantages, there is now growing evidence to suggest that cities with higher bicycling rates also have better road safety records. This study attempts to better understand this phenomenon of lower fatality rates in bike-oriented cities by examining 11 years of road safety data (1997–2007) from 24 California cities. The analysis included accounting for crashes across all severity levels, as well as for three classes of road users: vehicle occupants, pedestrians, and bicyclists. Additionally, we looked at issues of street and street network design to help determine the role that these features might play in affecting both bicycling rates and road safety outcomes. Overall, cities with a high bicycling rate among the population generally show a much lower risk of fatal crashes for *all* road users when compared to the other cities in our database. The fact that this pattern of low fatality risk is consistent for all classes of road users strongly suggests that the crashes in cities with a high bicycling rate are occurring at lower speeds. This agrees with the finding that street network density was one of the most notable differences found between the safer and less safe cities. Our data suggest that improving the streets and street networks to better accommodate bicycles may lead to a self-reinforcing cycle that can help enhance overall safety for all road users.

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Davis, California, often referred to as the bicycle capital of America since becoming the first city to gain "platinum" status from the League of American Bicyclists, should also be renowned for another reason: road safety. From 1997 through 2007, the years examined for this study, Davis experienced only 14 fatal road crashes within city limits, and 10 of those occurred on limited-access highways (CHP, 1997–2007). And despite a greater percentage of people biking to work than any other city in the United States, only two of these fatal crashes involved bicyclists. With a fatal crash rate in Davis of less than 2.1 per 100,000 residents over that time, far fewer people are killed on their roads than in the United States (US) as a whole, which averaged 14.8 fatalities per 100,000 residents over that same time frame.

Another American city recognized as a platinum bicycling city, Portland, Oregon, increased its bicycle mode share from 1.2% in 1990 to 5.8% in 2000. At the same time, the total number of road fatalities went from averaging over 60 per year around 1990 to fewer than 35 per year since 2000 (City of Portland Bureau of Transportation, 2008–2009). Moreover, there were only 20 total road fatalities in Portland in 2008, which is a remarkable safety record (3.6 fatalities per 100,000 residents) for a city of over 550,000 people. Although a number of factors other than bicycling are at play in these cities with regard to safety, the fatal crash rates in Davis and Portland compare extremely favorably with the countries reporting the lowest crash rates in the world, such as the Netherlands at 4.9 per 100,000 residents (Organisation for Economic Co-operation and Development, 2006), which happens to boast a bicycling mode share near 27% (Pucher and Buehler, 2008).

Conventional thinking about road safety would suggest that the outcome of lower road fatality rates with more

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bicyclists would be unlikely since, in general, bicyclists experience a much higher fatality rate per kilometer traveled than do drivers in the US—as much as 11 times higher (Pucher and Dijkstra, 2000; Mapes, 2009). To explain further, one might consider the alternate case of switching from driving to transit. Since transit is considered to be safer than driving on a per-kilometer basis, these former drivers who now use transit on a regular basis would have a lower fatality risk. Accordingly, a city with high transit use should, in theory, be safer than a city with a high mode share for driving. Since biking is generally regarded as riskier than driving on a per-kilometer basis, a city with a high level of bicycling should notionally be more dangerous. But given the growing evidence—from places such as Davis, Portland, and the Netherlands—suggesting that this is not the case, we decided to examine road safety data from 24 California cities—including Davis—in hopes of garnering evidence as to why cities with high rates of bicycle use frequently see lower rates of road fatalities for *all* road users.

To better understand the trends in these cities, we not only examine the number of crashes at different levels of severity but also the relative risk of a fatality or a severe injury when a crash occurs. These analyses were conducted for three classes of road users—pedestrians, bicyclists, and vehicle occupants—in order to help us understand whether the underlying patterns were similar for all road-user types. We also used US Census data as a rough estimate of the number of people walking, biking, and driving in each city in order to gain a better understanding of the relative exposure rates in these cities for the different classes of road users. Finally, we looked at issues of street and street network design to see what role these characteristics might play in affecting road safety outcomes.

Literature Review

Few studies have specifically looked at how safety varies for all road users depending upon the relative levels of walking or biking. Transit use, however, is one mode that has actually been considerably evaluated in terms of overall road safety. In an international study, Kenworthy and Laube (2001) concluded that cities with higher transit use also tend to have lower overall fatality rates. Litman (2009), in a separate study, found that the per-capita fatality rates in US cities were lower with increased transit use. One reason behind these results, as the authors point out, is that more transit use tends to lower the overall amount of vehicle use.

If reducing vehicle use through more transit use can improve overall road safety, then the idea that increases in biking and walking and an associated decrease in driving can have a similar effect seems promising. However, it is important to understand that the fatality rate in terms of kilometers traveled for vehicle occupants is approximately 10 times that for transit users; conversely, most studies have shown that the fatality rates in terms of kilometers traveled for biking and walking are higher than for driving (Pucher and Dijkstra, 2000; Mapes, 2009). One potentially confounding factor is that calculating safety on a per-kilometer basis might not be appropriate given that most biking and walking trips are generally a much shorter distance than driving trips, partly because bicyclists can sometimes access more direct routes unavailable to drivers. Considering the risk per trip made, instead of per kilometer traveled, might help level the playing field.

Another point to consider in examining why these cities with high levels of bicycling often have good safety records is the handful of studies examining the idea that individual bicyclist risk is not constant; rather, individual risk seems to decrease with an increasing number of bicyclists. In other words, bicyclists can find increased safety in higher numbers. For example, a 1996 study by Lars Ekman (1996) found no linear association between bicyclist exposure and conflict rate in a comprehensive study conducted in Sweden. More specifically, Ekman determined that the conflict rate for an individual bicyclist was higher when the number of bicyclists was low, with this conflict rate subsiding as the flow of bicyclists increased. In terms of conflict rate for a bicyclist, the number of bicyclists was actually more significant than the number of vehicles on the road. Conversely, Ekman found that the risk to pedestrians was not affected by the number of pedestrians.

Another example is taken from Copenhagen, where it was found that between 1990 and 2000, a 40% increase in bicycle-kilometers traveled corresponded to a 50% decrease in seriously injured bicyclists (Jensen, 2002). And in a 2003 study of California cities, Peter Jacobsen found results substantiating this idea of safety in numbers. Based on 68 California cities, but unfortunately for only one year of crash data, the results showed that the individual chance of a bicyclist or pedestrian being struck by a car drops with more people biking and walking (Jacobsen, 2003). And in a recent intersection-level study from Boulder, Colorado, the results suggest that the number the crashes per bicyclist decrease with bicycle volume (Nordback and Marshall, 2011). More specifically, more bicyclists on the road can help reduce crash risk for each bicyclist.

These results are relevant because conventional wisdom links an increase in exposure with an increase in risk. However, most researchers investigating the idea of "safety in numbers" hypothesize that drivers change their expectations, based upon their perceived probability of encountering a bicyclist. So when the number of bicyclists increases to the point where drivers begin to expect frequent conflicts with bicyclists, driver expectations and behavior could change for the better. Although not easily transferable to *overall* road safety, the findings in these studies do begin to suggest some explanation as to why places like Davis, Portland, and the Netherlands might be safer than places with lower bike use. While switching from driving to transit has been shown to decrease individual risk, switching from driving to biking or walking should, on average, increase individual risk. However, that average risk number does not explicitly consider situations where a critical mass of bikers and walkers may be able to experience improved safety in larger numbers, nor does it account for the reduced risk of bicycles to *other* road users as compared to the impact of cars.

While the concept that switching en mass from driving to biking or walking can actually increase overall safety seems possible despite average user risk statistics, another critical question is how cities can increase bicycling in the first place, and, more specifically, what community design elements lead to both a high level of bicycling as well as a good road safety record for *all* user types. In trying to increase bicycling, most strategies focus on street design elements such as adding bicycle lanes or even traffic-calming measures intended to reduce vehicle speeds (Pucher and Dijkstra, 2000; Retting, Ferguson, and McCartt, 2003). Our investigation accounts for street design features but also considers overall community design in terms of the street network.

The twentieth century witnessed a considerable shift in American street network design. While many observers focus on the US transition from the traditional gridded street layouts of the first part of the twentieth century to increasingly more dendritic, treelike street networks in the post-1950s period (Taylor, 2001), most overlook another factor that has led to increasingly sparser communities: street network density. Figure 1 illustrates the evolution of street network design for the last 100 years in the US, a period also known for a drastic increase in driving. Today, compact and connected street networks are increasingly being identified as a key ingredient in supporting transportation options beyond automobiles. Thus far, much of the existing research related to street network measures has concentrated on issues such as mode choice, physical activity, and obesity (Ewing and Cervero, 2001). Although the explicit relationship between street networks and road safety is beginning to garner more interest, the subject still has not been extensively studied (Ewing and Dumbaugh, 2009). The goal of this investigation is to move beyond the traditional approach of looking at just the characteristics of the street itself and examine the interrelated factors of street network density and street connectivity in terms of the degree of bicycling as well as road safety for all users.

Study Background

This research was based upon an initial database of all 473 California cities. We focused on California cities in order to help maintain consistency in the data, especially in comparing injury-severity outcomes. From this original database, we selected 24 cities for more a detailed analysis. The first factor in selecting these 24 cities was overall traffic fatality rate. All 473 cities were rank ordered by fatality rate from the highest to the lowest. The traffic fatality rate in this database ranged from 0.4 to 23.6 fatalities per 100,000 residents. We then selected 12 cities from the top half with relatively low fatality rates and 12 cities from the bottom half with relatively high fatality rates. The range of fatality

Figure 1. Evolution of street network design in the 20th century.

rates for the 12 safer cities was 1.3–5.5 fatalities per 100,000 residents compared to a range of 6.0–17.5 for the cities with poorer fatality records. In selecting these 24 cities, we also considered, to the extent possible, geography balance and factors such as compatibility in terms of population and average income.

For this study, we further subdivided the 12 safer cities into the following three groups by using bicycle mode share: high-bicycling cities, medium-bicycling cities, and low-bicycling cities. We did not perform this step for the cities with poor safety records because all 12 such cities also had low mode shares for bicycling. This is generally consistent with the larger database of 473 cities. In fact, in this large database, all cities with mode share greater than 2.5% for bicycling had traffic fatality rates that were less than 6.5 fatalities per 100,000 population. In other words, based on the distribution of fatality rates as a function of mode share, the 24 cities selected for detailed analysis are representative of the 473 cities in our original database.

These were the 24 California cities selected for further study:

Group 1: Highest-bicycling highest bicycling safer cities
  Berkeley
  Chico
  Davis
  Palo Alto

Group 2: Medium-bicycling medium bicycling safer cities
  Alameda
  San Luis Obispo
  Santa Barbara
  Santa Cruz

Group 3: Low-bicycling low bicycling safer cities
  Cupertino
  Danville
  La Habra
  San Mateo

Group 4: Less safe cities
  Antioch
  Apple Valley
  Carlsbad
  Madera
  Morgan Hill
  Perris
  Redding
  Rialto
  Temecula
  Turlock
  Victorville
  West Sacramento

Spatial Data

Journey-to-work data from the 2000 US Census was collected along with street network measures, street characteristics, socioeconomic data, traffic flow information, and over 230,000 individual crash records from 11 years of crash data. Other census data included household income levels, demographic information such as age and race, mode shares, and travel time to work. All of this information was geocoded in a GIS (geographic information system) database with the intention of facilitating a more comprehensive spatial analysis.

Crash Data

Fatal crash records for the years 1997 through 2007 were acquired from the Fatality Analysis Reporting System (FARS), whereas the nonfatal crash records as well as additional information regarding the fatal crashes were obtained from the California Highway Patrol (CHP) for this same period. From 2001 on, the FARS data included latitude and longitude information for crash location. Location information based on latitude and longitude was not part of the CHP record; rather, these crashes, and the pre-2001 FARS crashes, needed to be located by the name of the road where the crash occurred with respect to the nearest cross street. The cities selected for this study were limited to California in order to best maintain consistency between crash-severity outcome assessments; California specifies five levels of severity in their database: fatal, severe injury, visible injury, minor injury, and property damage only (PDO) (CHP, 1997–2007).

Each crash was geocoded into the GIS databases either based upon latitude and longitude information, if available, or to the nearest intersection on the street where the crash transpired. Overall, we successfully geocoded 238,856 of a total 241,915 crashes, or just under 99%.

Street Network Data

Street network data was obtained from the US Census TIGER/line files (TIGER means Topologically Integrated Geographic Encoding and Referencing system), the California Spatial Information Library, and the California Department of Transportation (CalTrans). Calculations for street network characteristics were conducted using ArcGIS in an effort to characterize street connectivity and street network density by using the link-to-node ratio and intersection density, respectively. The link-to-node ratio is calculated by dividing the number of links (road segments between intersections) by the number of nodes (or intersections), with the node count representing the total number of intersections, including dead ends or cul-de-sacs (Ewing, 1996). Generally, a link to node score of 1.4 or higher is typically considered to be indicative of a walkable community (Handy, Paterson, and Butler, 2003). Intersection density is one measure of street network density and is measured by the number of intersections per unit area, often a square kilometer or square mile.

Street-Level Data

For every arterial type street within each city, we collected information about the street design features list in Table 1. The data were averaged over the total length of major streets in each city; for instance, a value of 30 m for the curb-to-curb distance suggests that while arterial street widths tend to vary, the average width of the road cross section is 30 m within that block group. At the same time, a value of 0.6 for the bike-lane measure indicates that 60% of the length of major streets in that particular city includes a bike lane; if that value was 1.0, 100% of the major road length in that city includes a bike lane.

Results

For the purposes of this study, the crashes analyzed include only those that occurred on surface streets and not those on limited-access highways. This was done to compare crashes fairly on roads where walking and biking would reasonably be expected. Tables 2 and 3 summarize the data for this results section.

Table 1. Street design characteristics collected on all arterial roads

Total number of lanes*
Curb-to-curb distance*
Outside shoulder width*
Inside shoulder width (when a median is present)*
Raised median width*
Painted median width*
On-street parking**
Bike lanes**
Curbs**
Sidewalks**

*Average distance or number along the length of road.
**0 = no, 1 = yes, 0.5 = along one side of street.

Mode Shares

Based on 2000 Census journey-to-work data, Figure 2 depicts biking, walking, and transit use for each set of cities. Also shown is the US average for biking, walking, and transit use at 0.4%, 2.9%, and 4.6%, respectively (Pisarski, 2006). The high-bicycling cities in our study have 20 times more biking than the US average, more than 2.5 times more walking, and 1.5 times more transit use. The low-bicycling cities and less safe cities approximate the US average for biking but fall just below the US average for walking and transit use.

Overall vehicle mode share is well under 80% for the high-bicycling cities, 82% for the medium-bicycling cities, and over 94% for the low-bicycling cities.

Road Safety

In terms of road safety, the differences are not always found in terms of the overall crash numbers. In fact, the cities with the lower fatality rates would seem to be less safe if we looked only at overall crash frequency. This is an important distinction because many safety studies often focus more on the overall number of crashes and pay less attention to crash severity. In our results, an important difference seems to be related to what is happening after the crashes. The crash-severity risk outcome—based upon the percentage of crashes for each road-user type that result in a fatality—shows that if you are in a crash in one of the Group 4 cities, you are much more likely to die than if the crash was in a city from one of the other groups. Overall, the risk of a crash resulting in a fatality is similar for the three groups of safer cities for each road-user type. For the less safe cities, the chance of a vehicle occupant, pedestrian, or bicyclist crash resulting in a fatality is over 2.5 times greater than in each of the safer groups of cities.

Another key consideration in better assessing safety is relative exposure. With the intention of getting a better handle on the relative amounts of driving, biking, walking, and transit use in these sets of cities, we used a road-user exposure metric in which we multiplied city population by mode share to find a rough estimate of travelers using each mode of travel. This is similar to a methodology used by Jacobsen (2003); in his study, he

Table 2. Summary of results for crashes not on limited access highways

	Safer cities			
	High bicycling	**Medium bicycling**	**Low bicycling**	**Less safe cities**
General information				
Population (2000 average per city)	70,328	65,742	61,087	59,845
Population density				
People per sq. km	2,331	2,071	2,242	1,032
People per sq. mile	6,037	5,364	5,808	2,673
Income (2000 average)	51,669	46,579	81,721	46,408
Vehicle mode share	76.3%	82.0%	94.0%	95.8%
Estimated number of bicyclists	5,697	2,227	299	345
Estimated number of pedestrians	5,268	4,352	1,082	1,060
Estimated number of drivers[a]	53,625	53,908	57,422	57,302
Vehicle driver and passenger safety				
Fatalities	10.3	11.3	6.5	37.8
Severe injuries	61.5	52.3	52.5	83.1
Other injuries	2,315.5	1,878.5	1,861.3	1,673.0
Total injuries	2,387.3	1,942.0	1,920.3	1,793.8
Property damage only[b]	5,471.8	5,519.8	3,648.8	3,769.5
Fatality risk[c]	0.19%	0.15%	0.14%	0.76%
Fatality rate	1.0	1.1	0.6	10.3
Severe injury rate	6.0	5.0	5.1	22.6
Other injury rate[d]	224.3	181.0	168.4	455.0
Pedestrian safety				
Fatalities	6.3	7.3	3.8	15.5
Severe injuries	26.8	33.5	20.0	21.3
Other injuries	292.0	244.3	142.0	102.3
Total injuries[b]	326.5	286.3	166.3	140.4
Fatality risk[c]	2.47%	2.52%	1.82%	11.80%
Fatality rate	13.2	17.0	22.5	148.2
Severe injury rate	26.4	40.0	96.0	313.5
Other injury rate[e]	288.0	291.5	681.5	1,503.9
Bicyclist safety				
Fatalities	3.0	2.5	0.5	3.1
Severe injuries	24.5	32.8	11.8	48.3
Other injuries	539.0	398.0	202.3	111.1
Total injuries[b]	564.3	431.8	214.0	161.3
Fatality risk[c]	0.82%	0.58%	0.43%	2.2%
Fatality rate	7.0	9.0	28.8	349
Severe injury rate	22.3	76.4	203.9	2,185.2
Other injury rate[f]	491.5	928.5	3,510.0	5,022.1

[a] Estimates based upon mode share and population.
[b] Crash counts averaged per city for 1997–2007.
[c] Percent chance of a crash resulting in a fatality.
[d] Average per year per 100,000 estimated drivers.
[e] Average per year per 100,000 estimated pedestrians.
[f] Average per year per 100,000 estimated bicyclists.

assumed that even though journey-to-work trips represent a small percentage of total trips, the percentage of each mode for commuters is proportional to the percentage for all trips. Though this exposure metric is admittedly imprecise and might be inaccurate if we were interested only in absolute rates for vehicle, pedestrian, and bicycle safety, it should function adequately as a proxy for finding the *relative* safety rates for these 24 cities.

To put this approach into context, Figure 3 depicts the fatal crashes on surface streets over the 11-year study period for

Table 3. Street design features and street network characteristics

Street network & street design	Safer cities: High bicycling	Safer cities: Medium bicycling	Safer cities: Low bicycling	Less safe cities
Measure for street network density				
Intersections per sq. km	44.1	39.9	39.1	24.2
Intersections per sq. mile	114.2	103.2	101.2	62.7
Measure for street connectivity: link to node ratio[a]	1.39	1.38	1.25	1.29
Average centerline distance of highways				
Kilometers	7.5	7.2	9.0	9.4
Miles	4.7	4.5	5.6	5.8
Average centerline distance of major roads				
Kilometers	79.6	73.9	43.3	104.9
Miles	49.5	45.9	26.9	65.2
Average centerline distance of minor roads				
Kilometers	233.0	191.8	182.7	339.2
Miles	144.8	119.2	113.6	210.8
Average total centerline distance				
Kilometers	320.2	273.0	235.0	453.5
Miles	199.0	169.6	146.0	281.8
Sidewalks[b]	50.3%	38.3%	85.6%	48.4%
Bike lanes[b]	24.9%	23.6%	38.4%	15.6%
On-street parking[b]	41.1%	28.4%	42.8%	23.0%
Average number of lanes[c]	2.7	2.4	3.7	3.1
Average width of roadway cross section[c]				
Meters	15.5 m	14.3 m	18.2 m	16.6 m
Feet	50.9 ft	46.9 ft	59.7 ft	54.4 ft

[a] Number of links per number of nodes, including dead ends.
[b] Percent length of arterial/collector-type streets.
[c] Average on arterial/collector-type streets.

one city from the highest bicycling group, Santa Barbara, and one from the less safe group of cities, Rialto. These two cities have nearly the same population (ca. 92,000) with almost the same population density (ca. 1,900 people per square kilometer). Despite these similarities, mode share in Santa Barbara for bicycling is over 3.6% (on the low end of our eight higher-bicycling cities), whereas mode share in Rialto for bicycling is negligible at 0.2%. Mode share is over 6.5% in Santa Barbara for walking and 1.3% in Rialto. In terms of fatality rates, Santa Barbara had 19 vehicular deaths for our estimated 78,000 vehicle users over the eleven year period. This means a vehicle death rate of 2.2 per year per 100,000 drivers in Santa Barbara. In Rialto, with 68 vehicular deaths and an estimated 88,000 vehicle users over the same time frame, the vehicle death rate was over 7.0 deaths per year per 100,000 drivers. For walking, Santa Barbara experienced 14 deaths over 11 years with nearly 6,000 estimated walkers for a rate of 21.2 pedestrian deaths per year per 100,000 pedestrians. Rialto had 37 deaths with less than 1,200 estimated walkers for a rate of 284.3 pedestrian deaths per year per 100,000 pedestrians. Santa Barbara also had an estimated 3,319 estimated bicyclists with only 4 deaths over 11 years for a rate of 10.8 bicyclist deaths per year per 100,000 bicyclists. For Rialto, we find 3 bicyclist deaths but only 183 estimated bicyclists for a rate of over 165.2 bicyclist deaths per year per 100,000 bicyclists.

Now if we conduct this analysis for the city groups, we discover that even though the less safe cities have the lowest number of crashes, Table 2 shows that these cities also have higher vehicle-occupant crash rates across all severity levels. Another key consideration is that, even though the less safe cities had very low rates of biking and walking, they also experienced far more bicyclist and pedestrian fatalities than did the other groups of cities. For a pedestrian, the fatality rate is over 8 times greater in the less safe cities than in either of the city groups with significant biking, almost 10 times greater for a severe injury, and over 5 times greater for all other pedestrian injuries. For the safer cities with low bicycling, the pedestrian fatality rate is almost twice that found in the highest-biking cities.

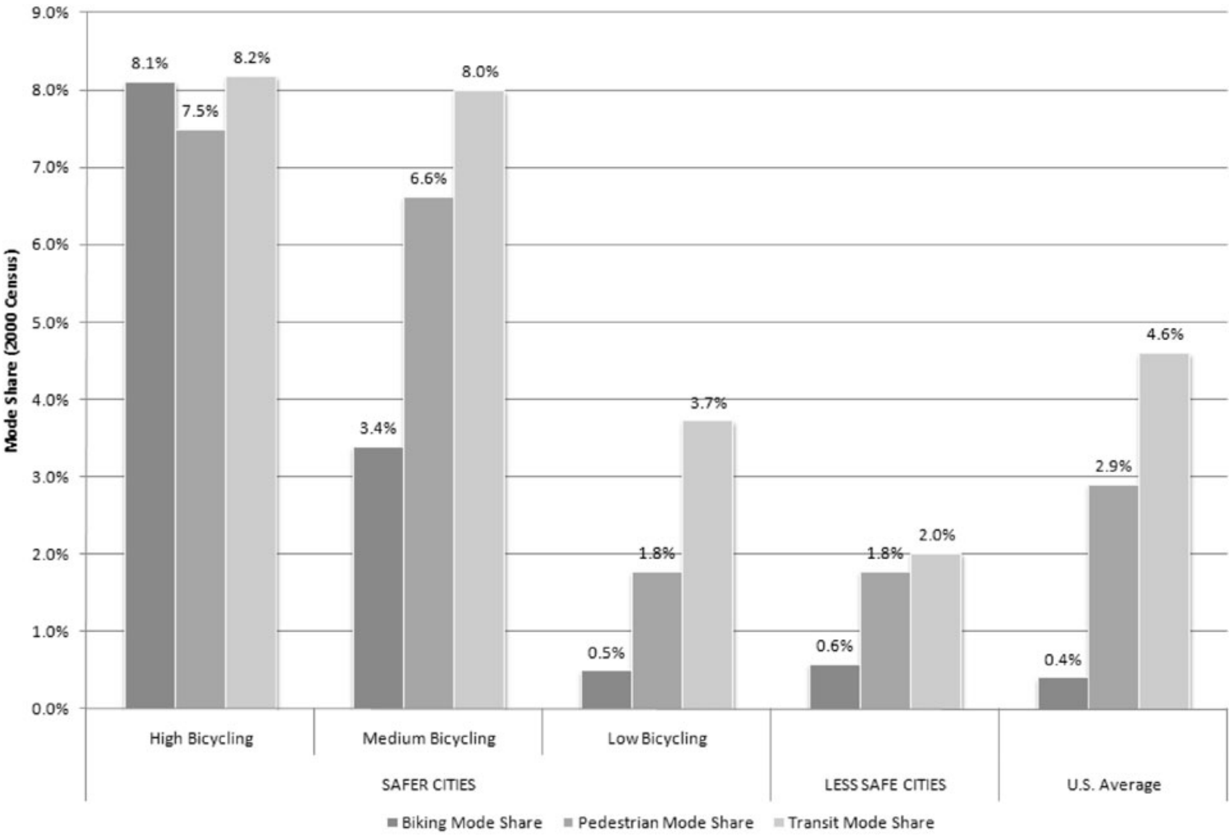


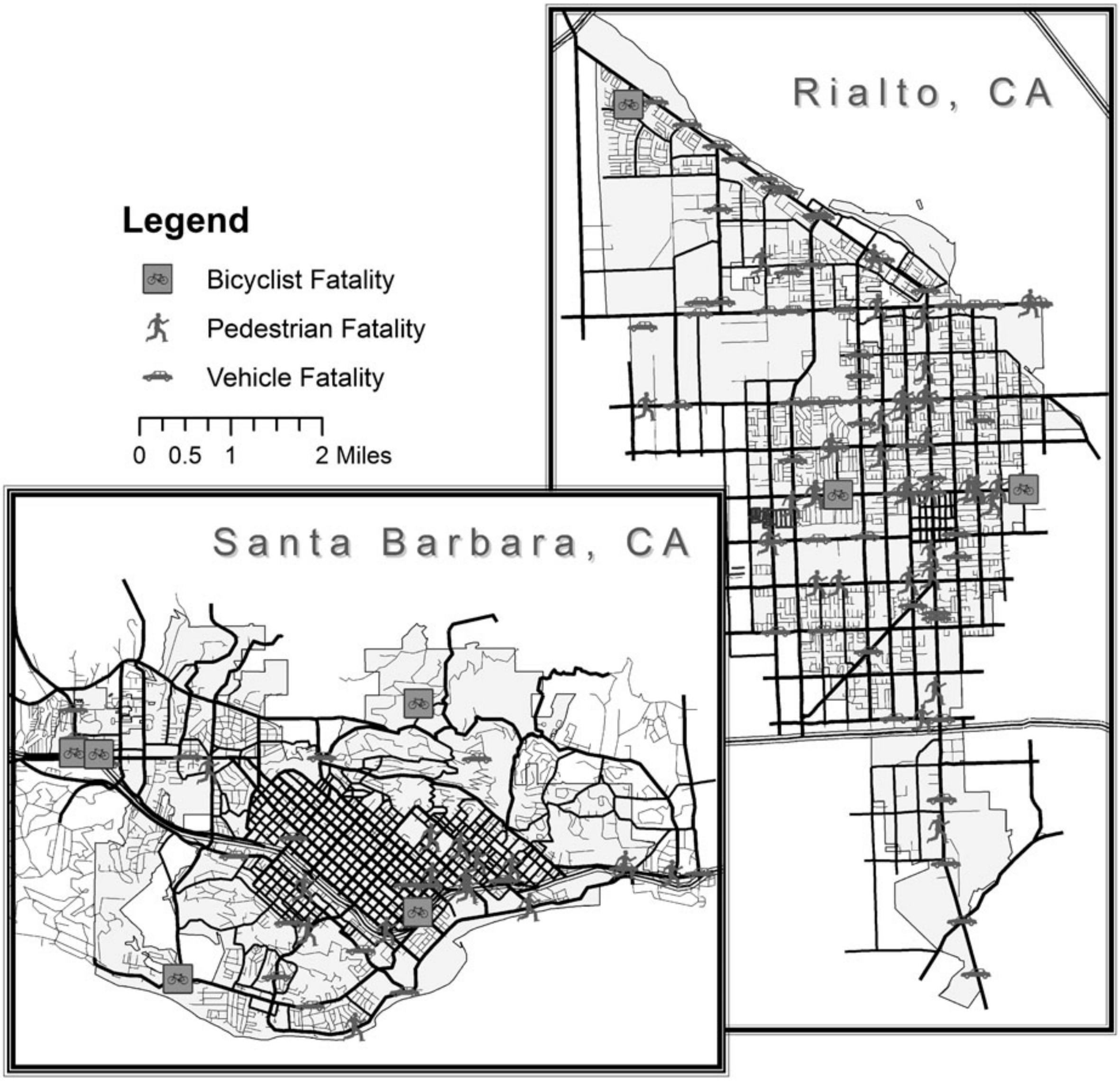
Figure 2. Bicycle, pedestrian, and transit mode shares (2000 US Census).

For a bicyclist, the fatality rate is more than 38 times greater in the cities with the poor safety records compared to those with significant biking, over 60 times greater for a severe injury, and over 7 times greater for all other bicyclist injuries. The safer cities with low mode shares for bicycling had only 2 bicycle fatalities. However, this is still more than 3 times the bicyclist fatality rate found in the cities with higher bicycling.

Street Network Characteristics and Street Design

Overall, the variation in relative fatality rates—as well as the fact that a crash occurring in one of the less safe cities has a much higher chance of resulting in a fatality—suggest differences in the way we build our cities in terms of the street network and in the design of the streets may be important factors. The data listed in Table 3 support these findings. One consistent element of all three groups of safer cities when compared to the less safe cities was higher intersection density, which is a measure of street network density. Although population density is not considered a street network measure, it does depict the same overall trends that we are seeing with intersection density. This correlation makes intuitive sense because, in most cases, we would expect population density to be related to street network density. Although we do observe a moderate correlation (Pearson correlation coefficient = 0.603), results from a previous study analyzing crash data at a much smaller level of geography (a US Census block group) showed street network density to have a much higher degree of association with crash outcomes across all severities than we found with population density (Marshall and Garrick, 2010). Thus, we will focus this discussion more on street network density, but note that differences in population density, and perhaps also the general dissimilarities between people's travel behaviors in urban and rural places might also tell part of the story.

Figures 4 and 5 enable a closer look at intersection density with respect to safety. For all road users, the chance that a crash would result in a fatality tended to be lower for the cities with lower-density street networks. This same trend was found for vehicle crashes, pedestrian crashes, and bicycle crashes.



		SANTA BARBARA	RIALTO
	Estimated No. of Drivers	78,367	88,043
	Estimated No. of Pedestrians	5,993	1,192
	Estimated No. of Bicyclists	3,319	183
	(estimates based upon mode share & population)		
Car	**Vehicle Fatalities**	19	68
	Vehicle Fatality Rate (avg. per year per 100,000 estimated drivers)	2.2	7.0
Ped	**Pedestrian Fatalities**	14	37
	Pedestrian Fatality Rate (avg. per year per 100,000 estimated peds)	21.2	284.3
Bike	**Bicycle Fatalities**	4	3
	Bicycle Fatality Rate (avg. per year per 100,000 estimated bikers)	10.8	165.2

Figure 3. Bicycle, pedestrian, and vehicle fatalities for Santa Barbara and Rialto, California (CHP, 1997–2007).

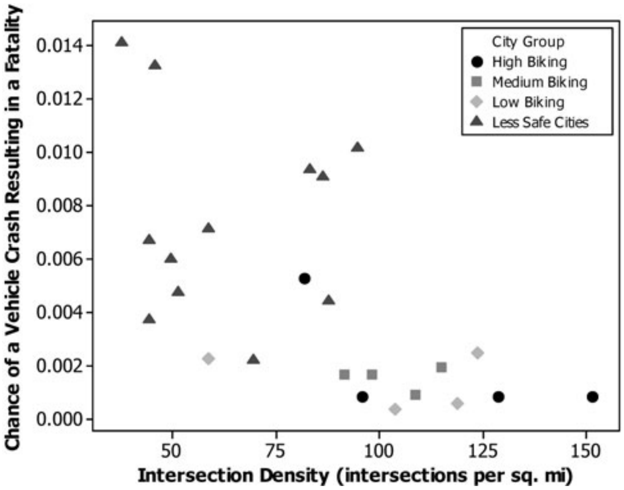


Figure 4. Chance of a vehicle crash resulting in a fatality vs. intersection density.

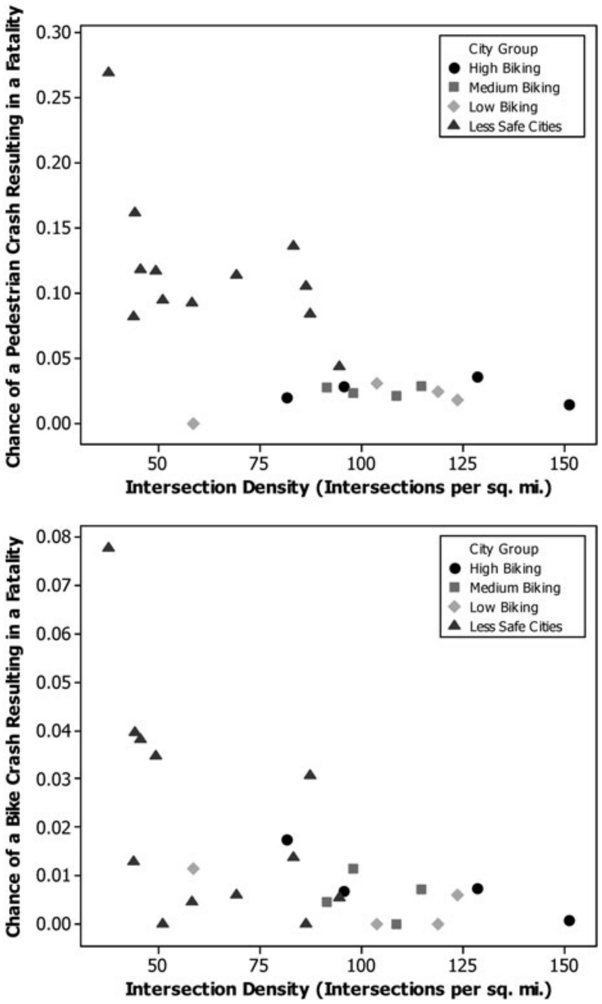


Figure 5. Chance of a pedestrian or bicyclist crash resulting in a fatality vs. intersection density.

It is important to note that there was also a consistent difference between the high-bicycling cities and the safer city group with low levels of bicycling. While similar in street network density, the key difference was that the street networks in these safer cities with high bicycling had a much higher degree of street connectivity as compared to the safe cities with low bicycling. Additionally, these high-bicycling cities also had major roads with fewer lanes and a narrower cross section than both groups of low-bicycling cities.

To help describe these findings, we will again use Santa Barbara and Rialto, as illustrated in Figure 3. Overall, Santa Barbara had the fewest average number of lanes on the arterial/collector roads of any city in the database, whereas Rialto averaged almost a full lane more on each major road. Santa Barbara also has more than three times the length of bike lanes on these same roads and about 30% more on-street parking—all of which seem to play some role in the road safety and biking/walking outcomes for Santa Barbara.

Although the presence of street design features such as bike lanes on major streets tended to equate to a better overall safety record, this was not always the case. Carlsbad—one of the less safe cities—also happens to have the highest percentage of bike lanes on the arterial/collector roads of all the cities in the database, with a bike lane on nearly 70% of the total length of these roads. However, Carlsbad is on the low end in terms of both street network density and street connectivity and also has the highest average number of vehicle lanes present on major roads of all the cities in the database. So even with a high degree of bike lanes present, Carlsbad's bicycle mode share is only 0.3%.

On the other hand, Berkeley—one of the safer cities—not only has one of the lowest percentages of bike lanes on major roads, but it also has one the highest biking rates. In this case, the difference from a place like Carlsbad might be that Berkeley has the highest street network density and street connectivity (especially for bicyclists) of all the cities. Because of these street network characteristics, Berkeley has been able to accommodate bikes by using so-called *bike boulevards* as opposed to the more typical accommodation of using bike lanes on major roads. Bike boulevards accommodate bicyclists on a connected network of minor streets.

Overall, the results suggest that certain street design features—such as bike lanes, on-street parking, and the number of travel lanes—aid in creating a transportation system with a higher degree of active transportation as well as with fewer fatalities on the roads. More specifically, while the safer set of cities all had high street network densities, it was the cities with both high street network density in addition to high street connectivity that had both good safety records as well as a high degree of bicycling and walking. Together, the street network features and the street network characteristics seem to work in concert toward helping create an environment with a high degree of active transportation as well as superior road safety.

Conclusion

The high bicycling cities in our study generally have a much lower risk of fatal or severe crashes for *all* road users when compared to many of the cities in our database. The fact that this pattern is consistent for all classes of road users strongly suggests crashes in these high-biking cities are at lower speeds. Such differences seem to be partly due to street network design but also due to other design elements that may well attract larger numbers of bicyclists. While the bicycle infrastructure itself might help in traffic calming, it may be that the actual presence of a large numbers of bicyclists can change the dynamics of the street enough to lower vehicle speeds. In fact, while other studies generally attribute the bicyclist "safety in numbers" effect to changes in driver behavior and awareness, safety for all road users may result from reaching a threshold of bicyclist volumes that compels cars to drive more slowly.

In terms of street network design, the clearest difference between the three groups of lower-fatality cities and the high-fatality cities was not street connectivity but rather street network density. Figures 4 and 5 show the relationships between fatality risks and intersection densities for vehicle occupants, pedestrians, and bicyclists, respectively. Our results consistently show that, in terms of street network design, high intersection density appears to be related to much lower crash severities. Our street design data also contain strong indications of these trends; for example, the high-biking cities tend to have more bike lanes, fewer traffic lanes, and more on-street parking. At the same time, large numbers of bicyclists might also help shift the overall dynamics of the street environment—perhaps by lowering vehicle speeds but also by increasing driver awareness—toward a safer and more sustainable transportation system for all road users. It is important to note that the high-biking cities in our database do not necessarily have lower overall crash rates; rather, they have much lower severity levels for those crashes that do occur.

Our results also show that a group of four cities has both low traffic severity levels and low bike use. These cities represent an interesting hybrid exhibiting some characteristics in common with both the high-bicycling/low-fatality cities as well as the low-bicycling/high-fatality cities. These four cities tended to have high street network densities similar to those found in the high-bicycling cities but at low levels of street network connectivity, more akin to the low-bicycling/high-fatality cities. In other words, this subset of cities featured local streets high in cul-de-sacs but at a relatively high density. These cities also revealed some other unique features that might contribute to their lower fatality rates, including far fewer major roads than found in the other city groups.

Overall, other factors appear to be at work in leading to these lower fatality rates for both the high-bicycling cities and the low-bicycling/low-fatality cities in addition to the street network and street design characteristics. In the case of the high-bicycling cities, these factors might include the work done to make the streets attractive to bicyclists, as well as the sheer presence of many bike riders. We do not yet have the data to disentangle the "safety in numbers" concept from the street and community design effects, but our results strongly suggest that safety benefits for all road users can be derived from an amalgamation of the steps taken to attract more bicyclists. While it is also important to point out that we do not have enough information to claim any causal relationship with this research, the trends do suggest that the issues of "safety in numbers" and street design are interrelated. In other words, improving the streets and street networks to better accommodate bicycles may in fact lead to a self-reinforcing cycle that can help enhance overall safety for all road users. This combination of factors seems to go a long way toward creating safer and more sustainable cities.

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