Why Bike-Friendly Cities are Safer for all Road Users

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ABSTRACT

Given the growing evidence suggesting that cities with higher bicycling rates find lower fatality rates, we examine road safety data from 24 California cities. This analysis included accounting for crashes across all severity levels but also for three different classes of road users: vehicle occupants, pedestrians, and bicyclists. Additionally, we looked at issues of street and street network design to see what role these characteristics might play in affecting road safety outcomes.

Overall, high bicycling cities generally show a much lower risk of fatal crashes for all road users when compared to most of the other cities in our database. The fact that this pattern of low fatality risk is constant for all classes of road users strongly suggests that the crashes are taking place at lower speeds. The most notable difference found between the safer and less safe cities was the density of street intersections. While we do not yet have the data to fully disentangle the various contributing factors, our results strongly suggest that safety benefits for all road users can be derived from a combination of the same steps that tend to attract more bicyclists. In other words, improving the streets to better accommodate bicycles may in fact lead to a self-reinforcing cycle that can help enhance overall safety for all road users.

INTRODUCTION

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 1996 through 2007, the years examined for this study, Davis endured only nine fatal road crashes, of which only three occurred on regular, non-limited access streets. And despite a greater percentage of people biking to work than any other city in the United States, not a single one of these fatal crashes involved a bicyclist. With a fatal crash rate in Davis of less than 1.5 per 100,000 residents, far fewer people are killed on their roads than in the U.S. as a whole, which average 14.5 fatalities per 100,000 residents.

Another American city recognized as a “platinum” bicycling city, Portland, Oregon, increased 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 (1). 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. Such fatal crash rates 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 (2).

These outcomes are not uncommon; other researchers have reported notable decreases in fatality rates in cities that have successfully increased their bicycle mode share (3, 4). Conventional thinking about road safety would suggest that the outcome of lower road fatality rates with more bicycle riders would be unlikely since, in general, bicycle riders experience a much higher fatality rate per mile traveled. But given the growing evidence suggesting that this is not the case, we examine road safety data from 24 California cities in this paper to garner evidence as to why cities with high rates of bicycle use typically see lower rates of road fatality for all road users. In other to better understand the trends in these cities, we not only examine the number of crashes of different severity levels but also the relative risk of a fatality or a severe injury given the fact that a crash occurred. These analyses were conducted for three classes of road users - pedestrians, bicycle riders and vehicle occupants - in order to help us understand if the underlying patterns were similar for all road user types. We also used 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.

STUDY BACKGROUND

This research was based on an initial database of over 150 California cities. We focused on California cities in order to help maintain consistency in the data, especially in comparing injury severity outcomes. The earlier papers based on this dataset concentrated on the street networks characteristics of 24 of these California cities representing twelve medium-sized cities with good safety records and twelve with poor safety records (5, 6). In this study, we further sub-divide the group of twelve safer cities into the following three groups of four cites based upon bicycle mode share: high bicycling cities, medium bicycling cities, and low bicycling cities. The cities included were:

Group 1: Highest Bicycling Safer Cities

- Berkeley
- Chico
- Davis
- Palo Alto

Group 2: Medium Bicycling Safer Cities

- Alameda
- San Luis Obispo
- Santa Barbara
- Santa Cruz

Group 3: Low Bicycling Safer Cities

- Cupertino
- Danville
- Cupertino
- San Mateo

Group 4: Less Safe Cities

- Antioch
- Apple Valley
- Carlsbad
- Madera
- Morgan Hill
- Perris
- Redding
- Rialto
- Temecula
- Turlock
- Victorville
- West Sacramento

Journey to work data was collected along with street network measures, street characteristics, socioeconomic data, traffic flow information, and over 230,000 individual crash records from eleven years of crash data. All of this information was geo-coded in a GIS database with the intention of facilitating a more comprehensive spatial analysis.

LITERATURE REVIEW

Few studies have specifically looked at how safety varies for all road users depending upon the amount of waking or biking that is occurring. Transit usage however is one mode that has in fact been evaluated in terms of overall road safety. In an international study, Kentworthy and Laube concluded that cities with higher transit use also tended to have lower overall fatality rates (7). Litman, in a separate study, found that the per capita fatality rates of U.S. cities were lower with increased transit use (8). 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 usage can help in terms of overall road safety, then the idea that increases in biking and walking can have a similar effect is promising. However, it is important to understand that the fatality rate in terms of miles traveled for vehicle occupants is approximately ten times that of transit users while most studies have shown that the fatality rates in terms of miles traveled for biking and walking are higher than for driving (8). One potentially confounding factor is that calculating safety on a per-mile basis might not be appropriate given that most biking and walking trips are generally shorter in distance than driving trips. Another point to consider is the handful of studies finding an increase in overall bicyclist and pedestrian safety emerging with increasing numbers of bikers and walkers. The thinking is that a driver changes his or her expectations based upon the perceived possibility of encountering a bicyclist or pedestrian. So when the number of bikers and walkers increases to the point where drivers begin to expect conflicts, the driver's behavior begins to change for the better.

For example, a 1996 study by Lars Ekman found no linear association between bicyclist exposure and conflict rate in a comprehensive study conducted in Sweden (9). To be more specific, 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 rates for a bicyclist, the number of bicyclists was more significant than the number of vehicles on the road. Ekman also found that the risk to pedestrians was not affected by the number of pedestrians.

Another examples is taken from the city of 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 (4). 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 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 (3).

These results are interesting because conventional wisdom links an increase in exposure with an increase in risk. Although not easily transferable to overall road safety, these studies do begin to suggest some explanation as to why places like Davis, Portland, and the Netherlands might be safety 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 would, on average, increase individual risk. However, that average risk number does not explicitly consider situations were there is a critical mass of bikers and walkers that may be able to find better safety in larger numbers. In those cases, the idea that switching from driving to biking or walking can actually reduce one's individual risk is a possibility. In terms of overall road safety, strategies known to increase biking and walking such as traffic calming and decreasing vehicle speeds have also been shown to lead to better road safety outcomes (10, 11). Together, such strategies could help to reduce overall vehicle miles traveled (VMT), which could also play a role in improving road safety (12).

RESULTS

For the purposes of this study, the crashes analyzed only include those that did occur on surface streets and not those on limited access highways. This was done in order to fairly compare crashes on roads where walking and biking would be reasonably expected. Tables 1 and 2 summarize the data for this results section.

Mode Shares

Based on 2000 Census journey-to-work data, Figure 1 depicts biking, walking, and transit use for each set of cities. Also shown is the U.S. average for biking, walking, and transit use at 0.4%, 2.9%, and 4.6%, respectively (13). The high-bicycling cities in our study have more than 20 times more biking than the U.S. average, more than 2.5 times more walking, and 1.5 times more transit use. The low-bicycling cities and less safe cities match the U.S. average for biking and fall below the U.S. 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 and the less safe cities.

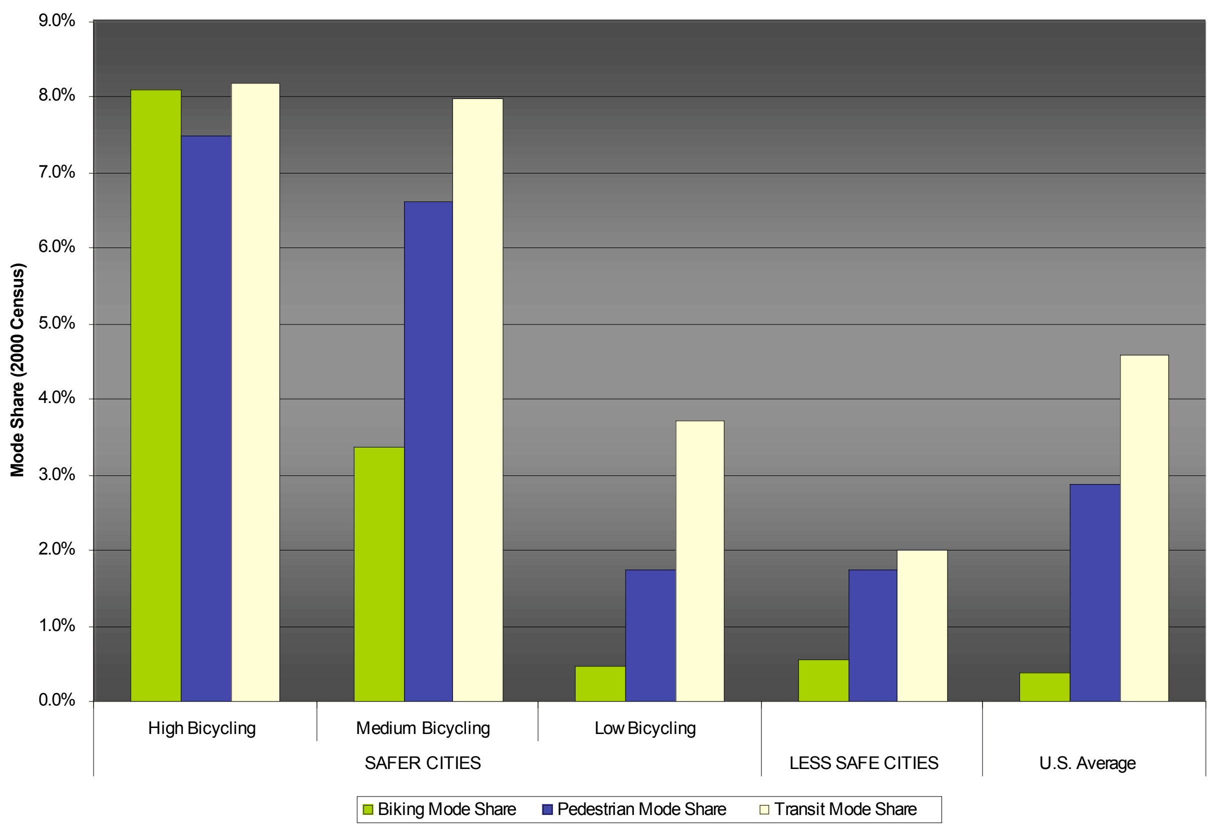


Figure 1 Bicycle, Pedestrian, and Transit Mode Shares (2000 Census)

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 only looked at overall crash frequency. This is an important distinction because many safety studies often focus on the overall number of crashes and ignore crash severity. In our results, another important difference seems to be in what is happening after the crashes occur. The crash severity risk outcomes - based upon the percentage of crashes for each road user type that result in a fatality - show that if you are in a crash in one of the Group 4 cities, then you are much more likely to die than if the crash took place in a city from one of the other groups. Overall, the risk of a fatality should a crash occur 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 or pedestrian crash resulting in a fatality is over four times greater than what we found in each of the safer groups of cities. Moreover, the chance of a bicycle crash resulting in a fatality is over 11 times greater in the less safe cities than in the safer cities.

Another key consideration in better assessing safety is considering 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 simple road user exposure metric in which we multiplied city population by mode share to find a rough number of travelers by each mode. This is similar to the method used by Jacobsen; in his study, he assumed that even though journey-to-work trips represent a small percentage of total trips, the percentage of each mode found for commuters is proportional to all trips (3). Though this exposure metric is admittedly imprecise and might be inaccurate if we were interested in absolute rates for vehicle, pedestrian, and bicycle safety, it should function adequately as a proxy toward finding the relative safety rates for these 24 cities.

To put this approach into context, Figure 2 depicts the fatal crashes not occurring on surface streets over the eleven year study period for one city from the highest bicycling group, Santa Barbara, and one from the less safe groups of cities, Rialto. These two cities have almost the same level of population (~92,000) living at almost the same population density (~5,000 people per square mile). Despite these similarities, bicycling mode share in Santa Barbara is over 3.6% (on the low end of our eight higher bicycling cities) while bicycling mode share in Rialto is nearly negligible at 0.2%. Walking mode share is over 6.5% in Santa Barbara and 1.3% in Rialto. In terms of fatality rates, Santa Barbara had 19 vehicular deaths with over 78,000 estimated vehicle users for a rate of 2.2 vehicle deaths per year per 100,000 drivers while Rialto had 68 vehicular deaths and over 88,000 estimated vehicle users for a rate of over 7.0 driver deaths per year per 100,000 drivers. For walking, Santa Barbara experienced 16 deaths over eleven years with over 6,000 estimated walkers for a rate of 24.2 pedestrian deaths per year per 100,000 pedestrians. Rialto had 39 deaths with less than 1,200 estimated walkers for a rate of almost 300 pedestrian deaths per year per 100,000 pedestrians. Santa Barbara also had an estimated 3,356 estimated bicyclists with only two deaths over eleven years for a rate of 5.4 bicyclist deaths per year per 100,000 bicyclists. For Rialto, we find one fewer bicyclist death but only 165 estimated bicyclists for a rate of 55.1 bicyclist deaths per year per 100,000 bicyclists.

Table 1 Summary of Results for Crashes <u>Not</u> on Limited Access Highways

		SAFER CITIES			LESS SAFE CITIES
		High Bicycling	Medium Bicycling	Low Bicycling	
General Information	**Population** *(2000 average per city)*	70,328	65,742	61,087	59,845
	Population Density *(people per sq. mi)*	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%
	Biking Mode Share	8.1%	3.4%	0.5%	0.6%
	Pedestrian Mode Share	7.5%	6.6%	1.8%	1.8%
	Transit Mode Share	8.2%	8.0%	3.7%	2.0%
	Estimated No. of Bicyclists	5,697	2,227	299	345
	Estimated No. of Pedestrians	5,268	4,352	1,082	1,060
	Estimated No. of Drivers	53,625	53,908	57,422	57,302
	(estimates based upon mode share & population)				
Vehicle Safety	**Vehicle Fatalities**	10.3	11.3	6.5	37.8
	Vehicle Severe Injuries	61.5	52.3	52.5	83.1
	Vehicle Other Injuries	2,315.5	1,878.5	1,861.3	1,673.0
	Vehicle Total Injuries	2,387.3	1,942.0	1,920.3	1,793.8
	Vehicle Property Damage Only	5,471.8	5,519.8	3,648.8	3,769.5
	(crash counts averaged per city for 1996-2007)				
	Vehicle Fatality Risk	0.19%	0.15%	0.14%	0.76%
	(% chance of crash resulting in fatality)				
	Vehicle Fatality Rate	1.0	1.1	0.6	10.3
	Vehicle Severe Injury Rate	6.0	5.0	5.1	22.6
	Vehicle Other Injury Rate	224.3	181.0	168.4	455.0
	(avg. per year per 100,000 estimated drivers)				
Pedestrian Safety	**Pedestrian Fatalities**	7.8	8.5	4.3	16.8
	Pedestrian Severe Injuries	26.8	33.5	20.0	21.3
	Pedestrian Other Injuries	292.0	244.3	142.0	102.3
	Pedestrian Total Injuries	326.5	286.3	166.3	140.4
	(crash counts averaged per city for 1996-2007)				
	Pedestrian Fatality Risk	3.07%	3.01%	3.01%	12.67%
	(% chance of crash resulting in fatality)				
	Pedestrian Fatality Rate	7.6	10.1	20.4	246.2
	Pedestrian Severe Injury Rate	26.4	40.0	96.0	313.5
	Pedestrian Other Injury Rate	288.0	291.5	681.5	1,503.9
	(avg. per year per 100,000 estimated pedestrians)				
Bicycle Safety	**Bicycle Fatalities**	0.8	1.0	0.0	1.8
	Bicycle Severe Injuries	24.5	32.8	11.8	48.3
	Bicycle Other Injuries	539.0	398.0	202.3	111.1
	Bicycle Total Injuries	564.3	431.8	214.0	161.3
	(crash counts averaged per city for 1996-2007)				
	Bicylist Fatality Risk	0.14%	0.22%	0.00%	1.36%
	(% chance of crash resulting in fatality)				
	Bicycle Fatality Rate	0.7	2.3	0.0	82.9
	Bicycle Severe Injury Rate	22.3	76.4	203.9	2,185.2
	Bicycle Other Injury Rate	491.5	928.5	3,510.0	5,022.1
	(avg. per year per 100,000 estimated bicylists)				

Now if we take this analysis to the city groups, we discover that even though the less safe cities have the lowest number of crashes occurring, Table 1 shows that these cities also found higher vehicle occupant crash rates across all severity levels. Another key consideration is the fact 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 the other groups of cities. For a pedestrian, the fatality rate is more than 24 times greater in the less safe cities than in either of the city groups with significant biking, almost ten times greater for a severe injury, and over five times greater for all other pedestrian injuries. For the safer cities with low bicycling, the pedestrian fatality rate is approximately twice that found in the higher biking cities.

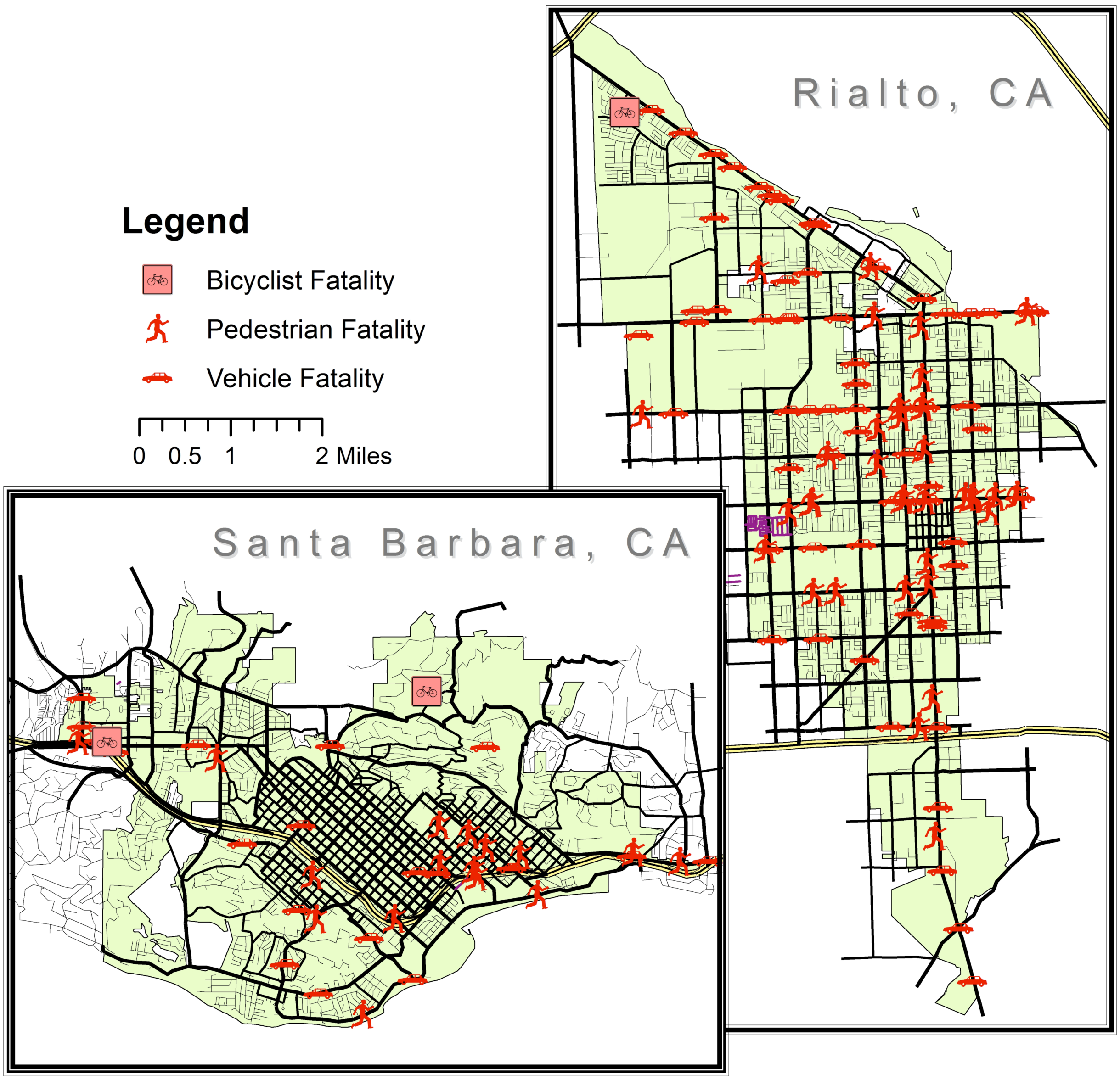


Figure 2 **Bicycle, Pedestrian, and Vehicle Fatalities for Santa Barbara & Rialto (1996-2007)**

For a bicyclist, the fatality rate is more than 75 times greater in the cities with the poor safety records compared to those with significant biking, over sixty times greater for a severe injury, and over seven times greater for all other bicyclist injuries. The safer cities with low bicycle mode shares had zero bicycle fatalities. However, in terms of all other injuries (including severe injuries) to a bicyclist, the crash rates were over 4 times greater in the low bicycling safe cities than in the higher biking cities.

Street Network Characteristics & 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, suggests differences in the street network and in the design of the street. The data shown in Table 2 supports these findings. The constant factor for all three groups of safer cities when compared to the less safe cities was intersection density. For the two groups of higher bicycling cities, they also tended to be slightly more connected with fewer lanes and a narrower cross-section on the major streets than both groups of low-bicycling cities.

Table 2 Street & Street Network Characteristics

Street Network & Street Design

	SAFER CITIES			LESS SAFE CITIES
	High Bicycling	Medium Bicycling	Low Bicycling	
Measure for Street Network Density				
Intersection Density *(intersections per sq. mi.)*	114.2	103.2	101.2	62.7
Measure for Street Connectivity				
Link to Node Ratio *(# links / # nodes including dead ends)*	1.39	1.38	1.25	1.29
Centerline Miles of Major Roads	49.5	45.9	26.9	65.2
Centerline Miles of Minor Roads	144.8	119.2	113.6	210.8
Total Centerline Miles	199.0	169.6	146.0	281.8
(average per city)				
Sidewalks	50.3%	38.3%	85.6%	48.4%
Bike Lanes	24.9%	23.6%	38.4%	15.6%
On-Street Parking	41.1%	28.4%	42.8%	23.0%
(% length of arterial / collector type streets)				
Avg. No. of Lanes	2.7	2.4	3.7	3.1
Avg. Width of Roadway Cross-Section	50.9'	46.9'	59.7'	54.4'
(average on arterial / collector type streets)				

In order to taking a closer look at intersection density with respect to safety, we developed the graphs shown in Figures 3 and 4. 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, as well as bicycle crashes.

As for the other street design considerations, we look again at Santa Barbara and Rialto shown in Figure 2. Overall, Santa Barbara had the fewest average number of lanes on the arterial/collector roads of any city in the database while Rialto averaged almost a full lane more. 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 a role in the road safety and biking/walking outcomes for Santa Barbara.

Another interesting example is Carlsbad - one of the less safe cities - which also happens to have the highest percentage of bike lanes on the arterial/collector roads of all the cities in the database with nearly 70% of the total length of these roads having a bike lane present. However, Carlsbad is on the low end of the street connectivity and street network density range and also has the highest average number of lanes present on these major roads 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 highest biking cities - has one of the lowest percentages of bike lanes present on the major roads. In this case, the difference might be in the fact that Berkeley has the highest street connectivity and street network density of all the cities as well as other strategies for accommodating bicyclists such as bike boulevards. This is certainly not to say that bike lanes are hazardous because the safer, high bicycling cities did in fact tend to have more bike lanes. For instance, Davis and Antioch find very similar population densities, street connectivities, and street network densities, but Davis has significantly better safety outcomes and also happens to cover almost 2.5 times more of their major roads with bike lanes. Overall, the results suggest that many of these street design factors, along with the street network measures such as intersection density, seem to work in coincidence toward helping create an environment with a higher degree of biking and walking as well as improved road safety.

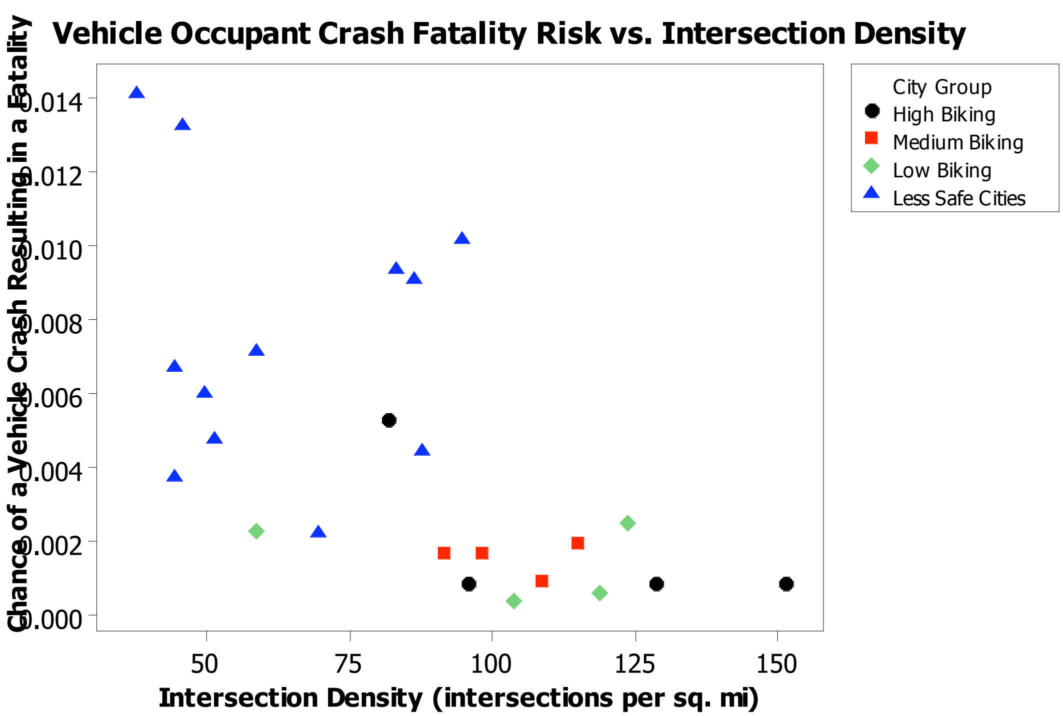
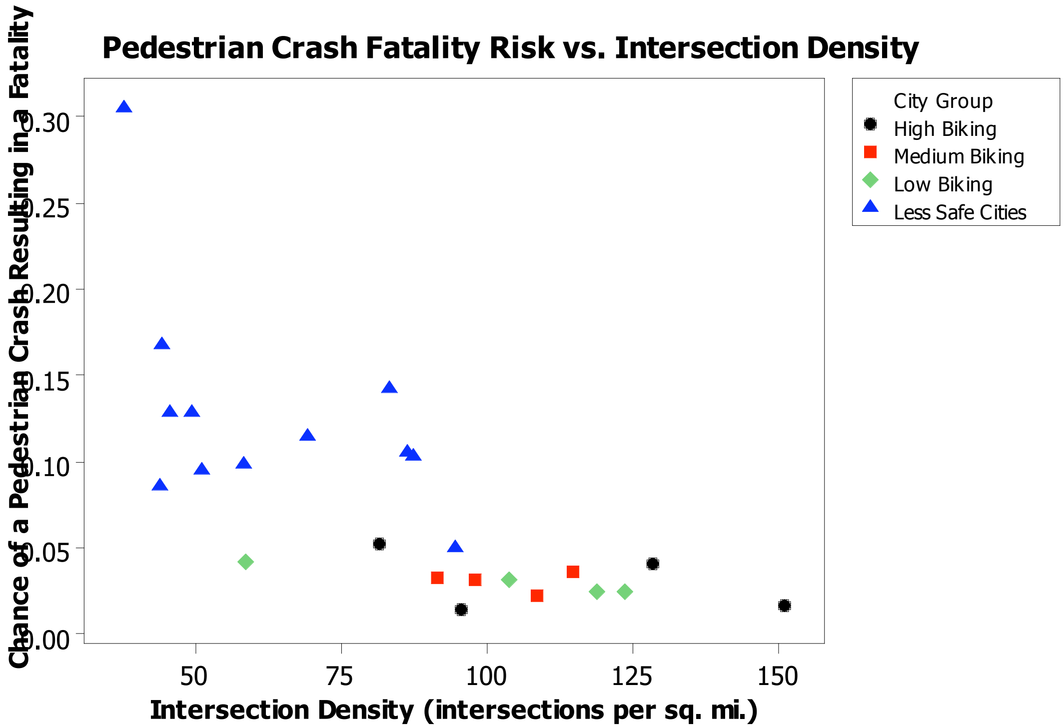


Figure 3 **Chance of Vehicle Crash Resulting in a Fatality vs. Intersection Density**



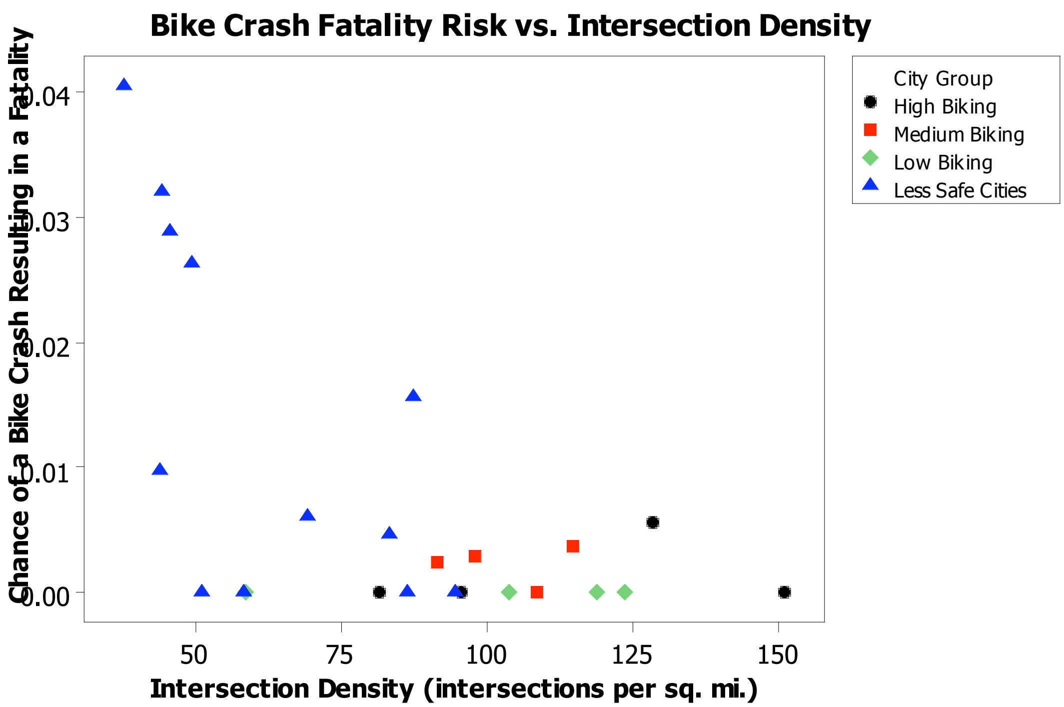


Figure 4 **Chance of a Pedestrian or Bicyclist Crash Resulting in a Fatality vs. Intersection Density**

CONCLUSION

High bicycling cities generally show a much lower risk of fatality or severe crashes for all road users when compared to many of the cities in our data base. The fact that this pattern is consistent for all classes of road users strongly suggests that the crashes are taking place at lower speeds in these high bicycling cities. The reason for lower speeds might be due to features such as traffic calming and other design elements that can help attract large numbers of bicyclists. Our street database contains some hints 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 bicycle users might also help lower vehicle speeds. It is important to note that the high biking cities 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 there is a group of four cities that have both low 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 intersection densities similar to the values found in the high-bicycling cities; they also tended to have 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 reveal 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, the biggest difference found between the three groups of lower fatality cities and the high fatality cities was intersection density. The graphs depict the relationships between fatality risks and intersection densities for vehicle occupants, pedestrians, and bicyclists, respectively. Our results consistently show that high intersection density appears to be the single most important street design factor affecting crash severity. However, there appears to be other factors at work in leading to these lower fatality rates for both the high-bicycling cities and the low-bicycling/low fatality cities. 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 these 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; that is, as long as we define safety in terms of reducing fatality and severe crashes and not just in terms of reducing overall rates of crashes. Improving the streets to 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 overall safer and more sustainable cities.

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