How the Presence of Bikeways affect Bicycle–Motor Vehicle Collisions: A San Francisco Bay Area Case Study

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Abstract Throughout the US, policies are being passed and funding is continually increasing to encourage the construction of bike facilities, yet few studies have researched the efficacy and safety differences between bikeways and roads and between the different classes of bikeways. This study examines whether the presence of bike paths (Class I), lanes (Class II) and routes (Class III) reduces injury rates from bicycle incidents involving motor vehicles. Using 2005-2006 car-bike collision police records from five Bay Area cities, the exact location of the accidents are pinpointed on GIS (Geographic Information System) maps. Seven analyses are completed that evaluate accidents among cities, classes, mid-block travel and intersections, while controlling for variability in bicycle population and the bikeway length to road length ratios. Results show that bikeways are associated with a decrease car-bike collisions rates when traveling mid-block, an increase in collisions when entering intersections, and no significant difference between accident rates when traveling on a bike lane or bike route. Findings suggest that more funding and attention be directed toward the intersection accident phenomenon on existing bikeways, and toward public education of vehicular bicycling skills.

Introduction

Bicycling is increasingly recognized not only as an alternative form of transportation, but for its cost effectiveness, energy efficiency, and physical health and environmental benefits (AASHTO 1999). In response to the growing bicycle population, local, state and federal agencies have and are continuing to implement bicycle-related projects and programs. As more bicycle facilities are constructed within each major city's transportation system, the volume of bicyclists also increases (Dill 2003). However, an increase in bicycling have also issued in an increase in bicycle accidents.

The first reported case of an automobile accident involved a collision with a bicycle. Since 1992, the first year bicycle injuries became documented in the U.S., there have been over 47,000 recorded bicyclist fatalities (Allen-Munly 2004). Motor vehicle collisions are the cause of over 90% of bicycle fatalities (MMWR). Thirty-Three percent of all bicycle fatalities result from automobile collisions in intersections (FHWA 1999). According to the National Highway Traffic Safety Administration (NHTSA) *Traffic Safety Facts 2005 Pedalcyclists,* there were 45,000 bicycle injuries involving motor vehicles in the US in 2005. This is why bicycle safety is so important and has become a pressing concern on government agencies and non-profit organizations.

In considering bicycle safety, there are three general areas in which to focus: equipment, bicyclist experience and facilities. Equipment denotes the condition of the bicycle, reflectors, lights, and other markings for visibility. The experience of the bicyclist relates to the skill and operating methods of the user. 'Bicycle facilities' is a general term to represent any provisions enacted by public agencies that accommodates and encourages bicycle use (AASHTO 1999). Such facilities include parking racks, storage, and bikeways. Bikeways are further divided into three classes: paths, lanes, and routes. The mere construction of these bikeways would seem to imply a resulting increase in bicycle safety. However, very few studies have been performed to verify this assumption. This study focuses specifically on existing bikeways and analyzes their effects on bicycle safety. It examines data collected from five cities in the Bay Area that supports or disproves the perceived idea that bikeways reduce bicycle-motor collision accidents and evaluates the difference, if any, these bikeways create. Because bicycle safety is among the top reasons why bike facilities exist in the first place, these findings will be important for actions carried out by government policy makers, bicycle coalitions and the bicycle-commuting public.

As defined by the American Association of State Highway and Transportation Officials (AASHTO 1999), a bike path (Class I), also known as shared-use path, is "a bikeway physically separated from motorized traffic that can also be used by pedestrians, skaters, joggers, and other non-motorized users." In contrast, a bike lane (Class II) is "a portion of roadway which has been designated by striping, signing and pavement markings for the preferential or exclusive use of bicyclists." Similar to the bike lane is a bike route (Class III), which is "any road or street designated for bicycle travel." These are for roads not wide enough to accommodate bike lanes and often include residential streets that have low speed limits. The alternative to these three classes of bikeways is to ride in the same lanes as motorized vehicles, on the shoulder, or on sidewalks.

Wachtel 1994 argues that while policies are being passed and money is being poured into countless projects and designs for bicycle facilities, little research is being done to understand the cause of bicycle-motor vehicle related injuries. Since his claim, studies have tried to understand bicycle safety by developing models for rating urban bicycle routes (Allen-Munley 2004, Allen-Munley 2006). Some have evaluated risk factors for several different bicycle facilities such as sidewalks (Aultman-Hall 1998), wide curb lanes (Hunter 2005), shared-use paths (Aultman-Hall 2005) and highway shoulders (Khan 1995). Houten 2005 discovered that pavement markings that designate a bike lane on the road caused motorists to become more aware of cyclists on the street. Some have also argued that the bicycle lanes may actually confuse the bicyclist when entering or turning in intersections, thus increase the risk of an accident (Allen 2003).

This study explores the following questions:

I. *Is the distribution of accidents among all Classifications the same for all cities?*

II. *Is there a negative relationship between amount of bikeways and accident rates?*

III. *Is there a difference between accident rates during mid-block travel on roads with bikeways and those without?*

IV. *Is there a difference between accident rates at intersections crossed by roads with bikeways and by those without?*

Methods

Study Area and Data The Bay Area cities represented in this study are: Alameda, Albany, Berkeley, Walnut Creek, and San Francisco (Fig. 1). These cities have been selected based on their variability in bikeway networks and their availability of police reports that include accident location. Berkeley and San Francisco local bike coalitions are very active, the bikeway networks are extensive and the populations are dense. In contrast, Walnut Creek is spread out and bikeway networks are limited. The Albany bikeway network is primarily comprised of bike paths (84%, Class I), whereas all others contain a rather even mix of all three classes.

Figure 1- Study Areas

For data on the bikeway networks and roads in these cities, this study made use of GIS data layers available by the U.S. Census, the California Department of Transportation, and the Metropolitan Transportation Commission (MTC) websites. The lengths of bikeways and roads were summed using the map attribute tables in ArcGIS. Intersections were individually counted using color print-outs of the ArcGIS maps. Bicycle accident information was solicited from regional police department traffic records for the year of 2005. Although the Berkeley accident data received is for 2004, it is assumed that the year variance is not great enough to affect the results. The estimated bicycle demand and map data remains unchanged because it is based on information recorded in 2000.

The accidents analyzed were restricted to those that involved only motor vehicles, for two reasons: these are the only bicycle injury records documented on a regular and ongoing basis, and motor vehicles are the chief players in bicycle injury and fatalities.

Classification of Accident Locations The police records specify the accident's location, which allowed the data to be positionally matched on the GIS maps. Using the program Arcmap, maps of city boundaries, roads, and bikeways were imported. The bikeway map for the particular city of interest was isolated, copied, and saved as a jpeg file. This jpeg file was then imported into GoogleEarth and overlayed onto the city of interest, transforming it to match bikeways precisely with its corresponding streets (Fig. 2). From there, the accident locations in that city can be easily searched and zoomed in on. Although GoogleEarth could not specify what the class type was, it became an efficient tool to locate the point of collision. Arcmap contained the attributes of the bikeway networks, and could be easily crossed referenced with GoogleEarth's map (Fig. 3).

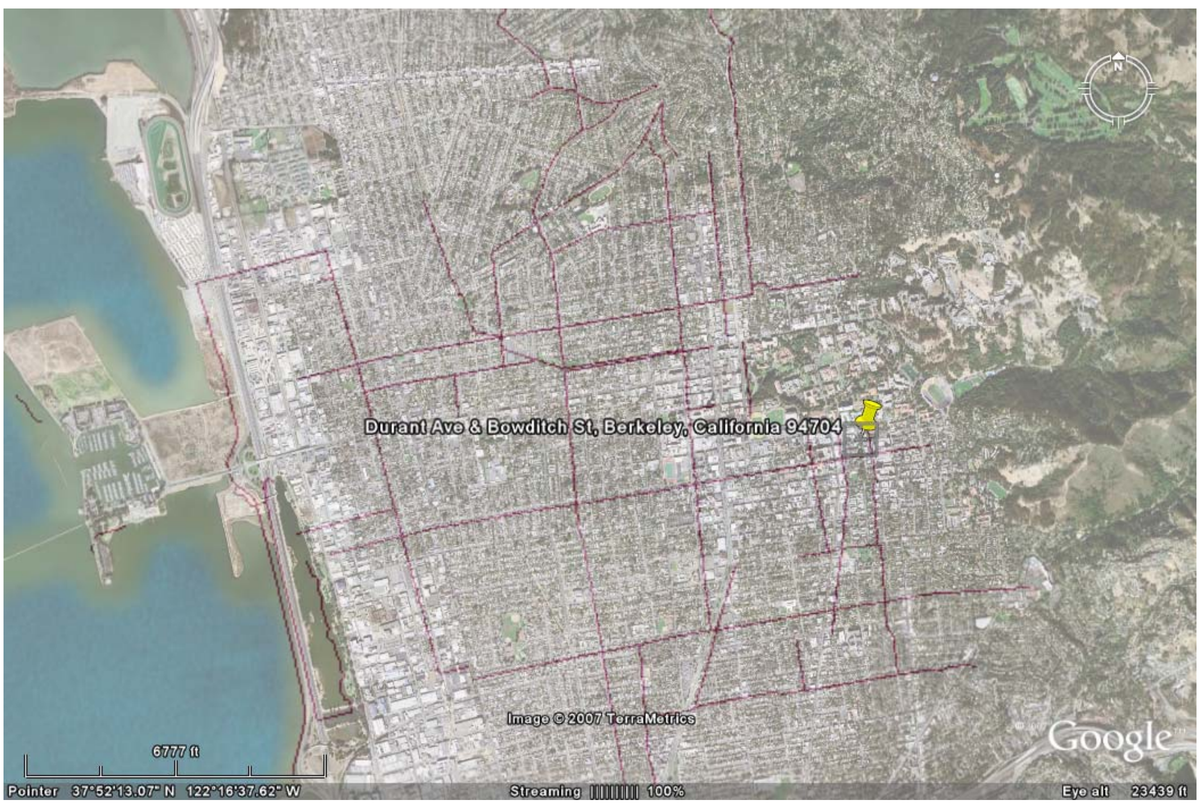


Figure 2 - GoogleEarth map of Berkeley with Arcmap bikeway overlay

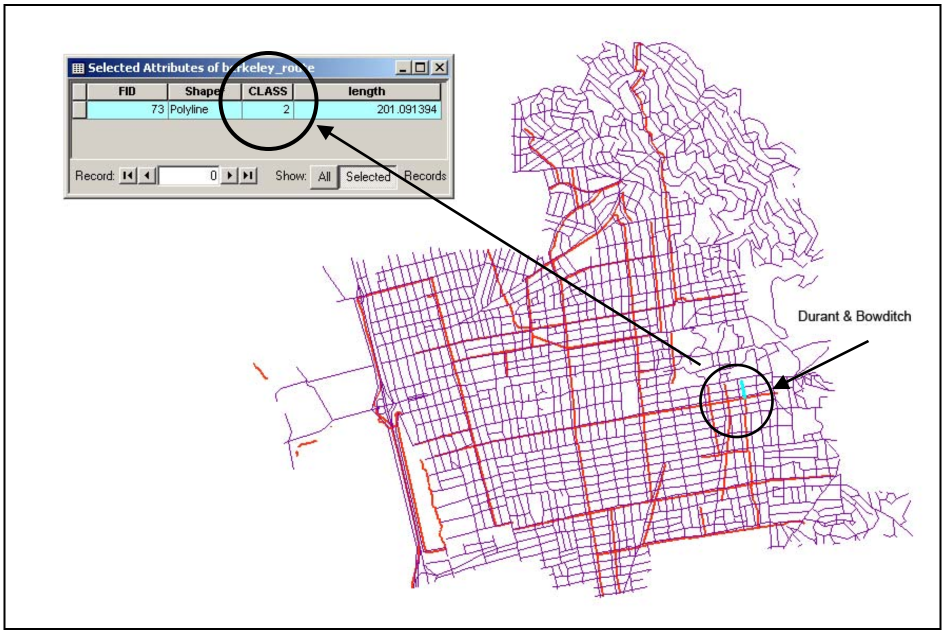


Figure 3 - Berkeley Map, using ArcMap to determine bikeway Class type

As different hazards exist for the bicyclist during mid-block travel and travel entering or within an intersection, these accidents were categorized separately. Mid-block accidents that did not occur on a bikeway were classified as "Road". Those that occurred on Class II or III were classified accordingly. Those that occurred in intersections were divided according to converging street types. A road crossing a road was labeled as "Road Int." and a road crossing any bikeway classes was labeled "Class Int.". The "Class Int.'s" were further classified according to the type of pathways that crossed. Where a Class I bikeway and road crossed, these were labeled "I/Road", where a Class II and road crossed, these were labeled "II/road", and so on. Figure 2 illustrates a breakdown of the classification process.

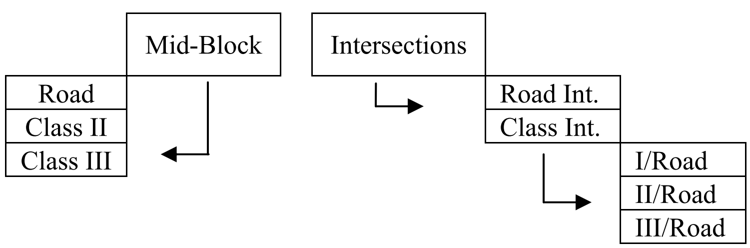


Figure 4 - Classification of Accident Locations

Given that bike paths (Class I) are off-street bikeways and separate from motor-vehicle traffic, it may be apparent that no collisions are to occur, but it is still important for this study to include Class I because they intersect roads with perpendicular motor traffic.

Estimation of Bicyclists The numbers for bicyclists for each city was estimated using Barnes' model for estimating bicycle demand. In his model, the best fit value for estimating the total number of bicyclists in an area is 0.3% of the population plus 1.5 times the reported commute share (Barnes 2005). Although the Barnes' model was designed to describe the United States as a whole and may not include important factors of the Bay Area that may affect the actual number of bicyclist (such as community and recreational behavior), as only Bay Area cities were compared, the error is assumed to be analogous for each city, and thus has not affected the outcome.

Variables Compared The five cities studied are not equal in size, bicycle population or total bikeway length. A greater number of bicyclists results in a greater number of accidents. More bikeway coverage within the city's road system produces a higher chance of an accident occurring on a bikeway. Likewise, more intersections crossed with a bikeway leads to a higher chance an accident occurs on a "Class Intersection". Therefore, the accident data needed to be controlled for these variables.

For each city, GIS maps were used to calculate these ratios: bikeway length to road length, Class I, II, and III length to road length, Class I, II, and III length to total bikeway length, number of road intersections to number of class intersections, and number of Class I, II and III intersections to total Class intersections. Using police reports and bicycle demand estimates, the ratio of the number of accidents to the number of bicyclists was calculated, determining an accident rate for each city. Depending on the analysis performed and the variables compared, these ratios were used to control for the differences among the cities that may have affected the accident data.

To answer the four aforementioned questions, seven analyses were performed. Using statistical software in Microsoft Excel, Table 2 presents the analyses and statistical methods used.

Table 2- Study analysis and corresponding model used

	Analysis	**Model**
I	Distribution of Accidents Between Cities	Contingency Table
II	Relationship between Bikeways and Accidents	Linear Regression
IIIa	Roads Vs. Bikeways (Mid-block)	Chi-Squared Test
IIIb	Class II vs. Class III (Mid-block)	Chi-Squared Test
IVa	Roads Vs. Bikeways (Intersection)	Chi-Squared Test
IVb	Class I vs. Class II vs. Class III (Intersection)	Chi-Squared Test
IVc	Relationship between Intersection Accidents and % Bikeway coverage	Linear Regression

Analysis I *Is the distribution of accidents among all Classifications the same for all cities?* For this question, the null hypothesis (H_o) is: the distribution of accidents in the different classifications (Fig. 4) is *equal* among all cities. To test this hypothesis, the data was arranged in a contingency table. If the Chi-squared value (x^2) is *equal* or *greater* than the appropriate critical value, then H_o is rejected, concluding that accident frequencies are not the same among the cities. The variation in bicycle population is corrected for by multiplying the accident data by the ratio of the city specific bicycle population to the sum total bicycle population of all five cities. For example, looking at 88 "Road" accidents in San Francisco, with a bicycle population of about 15,000, and a sum total bicycle population of about 22,000: 88 x (15,000/22,000) = weighted accident data for SF "Roads". The purpose of this analysis is to determine if the unequal distribution of bikeway networks among the five cities show any difference in their occurrence of accidents.

Analysis II *Is there a negative relationship between bikeways and accidents?* In other words, does a higher percentage of bikeway length to road length result in a lower number of accidents per number of cyclists. Tested using the linear regression model, the independent variable (x) is the % bikeway (Class I, II and III) length to road length per city and the dependant variable (y) is the # number of accidents to the number of cyclists per city. The five points plotted represent the five Bay Area cities. The correlation coefficient (R^2) corresponds to the strength of the relationship between x and y. The value varies between 0 and 1, where 1 indicates that the regression line fits the real data perfectly. If the slope is positive, it implies that more bikeways correlate to a higher accident rate. A negative slope suggests that more bikeways are associated with a lower accident rate.

Analysis IIIa *Is there a difference between accident rates during mid-block travel on roads with bikeways and those without?* The H_o, in this case, is that there is *no* difference between accidents on roads with and without a bikeway during mid-block travel. To test the null, data from all cities were pooled. Using a Chi-squared (χ^2) test, the probability value (*p)* determined whether the discrepancy in the number of accidents was due to chance rather than a real difference in risk. Only when $p<0.05$, can the H_{o2} can be rejected, and the alternate hypothesis that there *is* a difference, is assumed to be true. In order to ensure that more accidents were not occurring on roads simply because there are more roads than bikeways, the data was controlled by applying the sum total of all five cities bikeway length to road length ratios. **IIIb** The second component to this analysis determined if a difference in accident rates existed when on a lane (Class II) or route (Class III) during mid-block travel. (H_o: There is *no* difference in accidents when traveling on Class II or III) This data was also pooled and tested using a χ^2 test. Accident data was corrected for unequal lengths of bike path, lane and routes using the Class II and III length to the sum of Class II and III length ratios. A significant p-value revealed a disparity in bicycle safety within the different classes of bikeways.

Analysis IVa *Is there a difference between accident rates at intersections crossed by roads with bikeways and by those without?* For this study, an intersection defines the cross-convergence of streets. It does not account for the intersection of driveways. The purpose of this analysis was to determine if intersections, when traversed with a bike path, lane or route, experienced a higher accident rate than intersections without bikeways (H_o: There is *no* difference). This data was pooled from all cities. In order to assume that the chances of an accident occurring in one of these intersections is equal, the accident data was weighted with the ratio of the number of intersections *with* a bikeway to number of intersections *without* a bikeway. A χ^2 test determined whether to accept or reject H_o. A rejection concludes that aside from random chance, one causes more collisions than the other. **IVb** The second part of this analysis considered whether the accident rates in bikeway intersections varied with the bikeway Class type. The null states that, there is *no* difference in Class I, II, or III intersection accidents. After controlling for the variability in the quantity of Class I/Road, II/Road, and III/Road intersections, a χ^2 test determined whether or not to accept $H_{o.}$ **IVc** The purpose of this analysis is to find the relationship between the number of accidents occurring in the intersections with bikeways and the percent bikeway coverage. To contrast this relationship, a second regression is applied to the relationship between the numbers of accidents occurring to the % road coverage without bikeways on them. The relationship looks like this:

$$(X) \quad \frac{\text{\# of accidents at intersections}}{\text{bicycle population}} \quad \text{Vs.} \quad (Y) \quad \text{\% amt. roads with/without bikeway}$$

Results

From a total of 433 bicycle-motor vehicle accidents, 48% occurred in intersections, 26% in intersections with a bikeway, and 17% on bikeways during mid-block travel. Of the five cities studied, Alameda not only had the highest percent of bikeway network coverage, but also the highest number of accidents per cyclist rate. The primary collision factors were improper or unsafe turning (of bicycle or vehicle), and bicycle travel at an unsafe speed. The most common accidents were broadside and sideswipe collisions. Broadside collisions, also referred to as T-bone collisions, are where the side of the bicycle is impacted by the front of a vehicle, or vice versa. Sideswipe collisions are where the bicyclist and motorist are traveling parallel to each other and make contact.

As predicted, no collisions were reported on bike paths (Class I) during travel between intersections. Surprisingly, only 3 collisions were reported in zones where Class I intersected a Road. Because of this, Class I was excluded from Analysis IVb; further reasoning is presented in the 'Discussion'.

Analysis I – Distribution of Accidents Among Cities Table 3 presents the data from which the calculated values input into the contingency table were derived. In order that the values are standardized, '#of accidents' is multiplied by the rows '% Ratio'. The x^2 value calculated from this test is 0.911. When the critical values table of the Chi-Square distribution is consulted (Zar 1999), it shows that the critical value is 26.30 (d.f. = 16, $\alpha = 0.05$). Because x^2 is much smaller than the critical value, the null hypothesis (H_{o1}: the distribution of accidents in the different classifications is *equal* among all cities) is accepted. It is then concluded that, the columns (Cities) are independent of the rows (Classifications) and the extent of the bikeway network in each city does not affect accident frequency among the classifications.

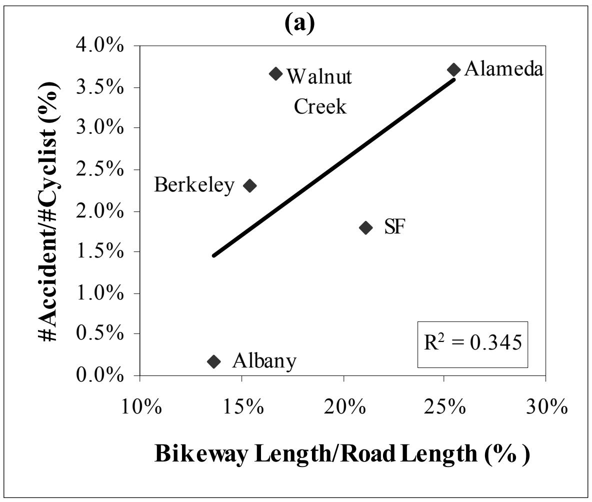
Table 3 – Number of Accidents per Classification per City, *x² value* from Contingency Table test

City	Classification: Road	Class II	Class III	Road Int	Class Int	% Ratio; City Bike Pop. To Total Bike Pop.	***x²***	***critical value***
SF	88	26	31	49	71	68.0%		
Berkeley	45	7	3	34	24	22.6%		
Alameda	14	4		6	13	4.6%		
Walnut Creek	5	2		7	3	2.1%		
Albany	1					2.6%		
							0.911	**26.30**

To test this hypothesis further, all possible combinations of cities (i.e. SF-Berkeley, SF-Alameda, etc.) were also compared using a chi-squared test. No significant differences were found between any of the cities.

Analysis II – Relationship between Bikeways and Accidents Graph (a) in figure 5 shows that the relationship between the percent of bikeway coverage in each of the 5 Bay Area cities and the associated accident rate is positive. This positive relationship implies that as more bikeways are constructed within the city, higher accident rates will be seen. However, the R^2 value of 0.345 indicates that this relationship is not strong and only 35% of the variability in the data is explained by this regression.

It seemed anomalous that Albany had only 1 bicycle collision for the year of 2005, so the data point was removed and tested to see how the regression changed. Graph (b) also shows a positive correlation, although slight, but has a *much* weaker relationship ($R^2 = 0.0685$).



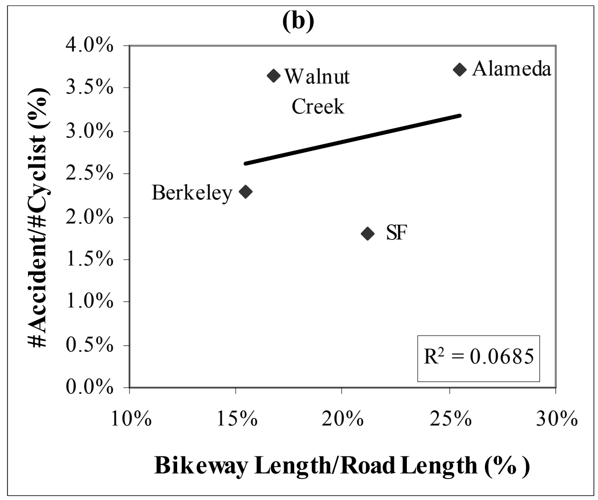


Figure 5 – Linear Regression of percent bikeway coverage to accident rate per city (a) with Alameda data (b) without Alameda data

Analysis III – Collisions in Mid-Block Travel Two separate hypotheses were tested as to consider bicycle collisions during Mid-block travel. The left half of Table 4 shows the number of accidents reported and the length ratios used to standardize the values. The important column to look at is 'p-value', for it determines whether or not a significant difference exists between the two classifications being compared.

The first hypothesis, there is *no* difference in accident rates between Bikeways and Roads, was rejected. A p-value of 2.05E-22 suggests that this difference is highly significant. The second hypothesis, there is *no* difference in accident rates between Class II and Class III bikeways, was accepted (p=0.170). These results conclude that roads *with* bikeways reduce bike-car collisions when compared to roads *without* bikeways. No significant difference can be seen between accidents occurring on bike lanes and those occurring on bike routes.

Analysis IV – Collisions in Intersections The right half of Table 4 shows the number of accidents reported in the different categories and the % ratios used to standardize the data.

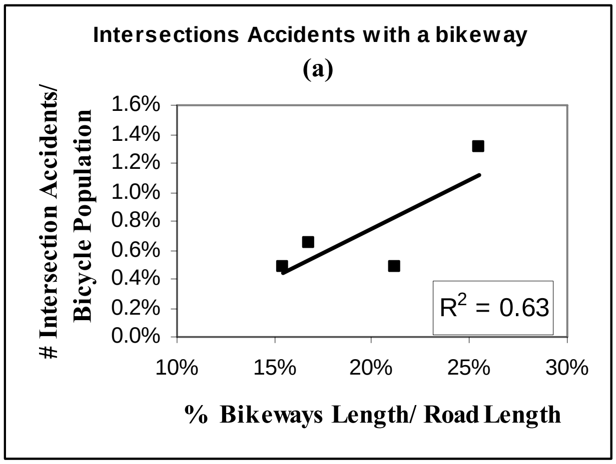
According to the p-values calculated from the χ^2 test, there was a statistically significant increase of collisions in intersections where a bikeway crossed a road when compared to intersections where a bikeway had not crossed. However, there is no significant difference in accidents rates between roads intersected by a bike lane and those intersected by a bike route.

In some cases, Classes crossed each other. However, because the occurrence of an accident in those areas was so small, it was not a point of concern and therefore was not included in this analysis.

Table 4 – Comparisons among Roads, Bikeways, and Classes for Mid-block and Intersection Accidents, ratios given are values used to control data, *p-values* from χ^2 tests.

Comparison	Mid-block Accidents: # Reported	Mid-block Accidents: % Length Ratio; Road/Bikeway to Total Road	*p-value*	Intersection Accidents: # Reported	Intersection Accidents: % Ratio; # of Road/Bikeway Int. to Total # of Int.	*p-value*
Road	153	83.5%		153	83.5%	
vs.						
Bikeway	73	15.6%		73	15.6%	
			2.05E-22			**3.96E-10**
		Class II/Class III to Total Bikeway			# of Class II/Class II Int. To Total # of Bikeway Int.	
Class II	39	26.3%		39	26.3%	
vs.						
Class III	34	51.4%		34	51.4%	
			0.170			**0.164**

Although the above results have already implied that roads intersected with a bikeway experience a higher rate of accidents, the findings in Figure 6 are still very interesting. The points on the graph represent the cities; Albany is not shown because no accidents in intersections occurred. Graph (a) shows that as more bikeways are present in a city, there is a higher rate of accidents occurring at these intersections. Although graph (b) shows a similar relationship, the strength of the relationship between % coverage of roads without bikeways and accidents occurring in those intersections, is not nearly as strong ($R^2 = 0.63$ vs. 0.24).



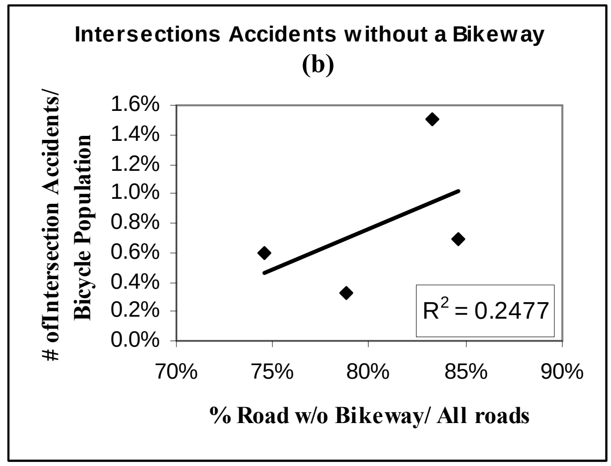


Figure 6 – Linear regression of (a) the % coverage of bikeway length to number of accidents occurring on intersections with bikeways (b) the % coverage of roads without bikeways to the number of accidents occurring in these intersections.

Discussion

Important findings in this study imply that the existence of bikeways have not proven to decrease the overall occurrence of bicycle-motor vehicle collision rates. It was also interesting to see that there is a positive relationship between bikeways and accident rates among the cities, although not significant. Other results show an increase in bicycle safety for mid-block traveling on bike lanes and routes, but it is difficult to say whether these bikeways create an increased overall safety to bicyclist traveling on these. The sole purpose of bike lanes and routes is to protect the bicyclist from adjacent vehicles in same-direction travel in mid-block zones. All other hazards are still present. Roughly half of all accidents in this study occurred in intersections, which coincides with a previous study that states that intersections are a major point of conflict between bicycles and motor vehicles (Wachtel 1994). Of the intersection accidents, significantly more accidents occurred in intersections *with* a traversing bikeway than in intersections without a one.

The argument that bike lanes actually confuse the bicyclist in intersections and may be a danger rather than a safeguard is partially supported by this study's findings. The idea that bike lanes confuse the bicyclist arises from the nature of the bike lanes. Bike lanes are designated lanes, usually painted on the right side of the road. In the event where the bicyclist needs to turn left, it requires them to enter into traffic and merge to the other side of the road. In contrast, bike routes do not have a separate designated lane and therefore would not experience the same 'confusion' with that of a bike lane. So, although my results show there *is* a difference in

'Bikeway Int' and 'Class Int' accidents, it also shows that there is *no* difference between bike lane and bike route intersection accidents. The idea that bike lanes are 'confusing' in intersections is not consistent with my results. If it were, bike lane intersection accidents would be significantly higher than those that occurred in bike route intersections. It causes me to wonder: if bike routes are generally on roads with lower traffic volumes and speeds, where the only difference of a route from a road is simple pavement markings, then why is there a significant difference in intersection accident rates where these routes exist? A possible explanation to this phenomenon is that the hazards impended on the bicyclist when entering an intersection is equal among all types of intersections, but because more time is spent traveling on roads with bikeways rather than on roads without them, more collisions in these bikeway intersections will result. This can be supported by the findings in 'analysis II', which implies that a higher percent of bikeway coverage on the roads relate to a higher overall accident rate. Further study should be done to understand the different conditions of bikeway intersections and what can be done to reduce the risk of accidents in these areas.

Although bike paths also intersect roads, these zones have not proven to be of significant concern. Bike paths are generally used for recreational bicyclists traveling at low speeds and unusable for fast-paced riders (Allen 2005). Because of the different 'type' of bicyclist who rides on bike paths, it is assumed that their risk factors are not the same for those who travel on lanes and routes. In order to eliminate as many confounding factors as possible, the data was removed from analysis IVb.

Limitations Surprisingly, local bicycle coalitions could not present any strong figures on the number of bicyclists in each city. A member of the San Francisco bicycle coalition provided a 'conservative' estimate of 40,000 bicyclists in San Francisco. This number reflected his idea that the US Census states that bicycle commuters comprise 2% of the city's population and a phone survey done by David Binder and Associates states that 5% of the city's population rides bikes. I could not find documentation of the phone survey and the 2000 US Census states that bicycle commuters comprise 2% of the *commuting population*. I resorted to Barnes' model, which based on Census data and a best-fit model he found to represent bicycle demand for the average U.S. city. According to this model, San Francisco's bicycle demand is 8,300. Although this number is much less than the S.F. coalition's projected account, it is the only model that can be used to generate bicycle demand across all cities in this study. Assuming that the Bay Area is well known for its attention to alternative transportation and use of bicycles, the low estimates would be relatively the same for all cities within this study, and therefore would not have a large effect on the outcome.

Unfortunately, not all bicycle-motor vehicle accidents are reported. Those involved in a collision may choose not to deal with the interference of the law and insurance agencies. Others may experience only minor injuries and have no need for a report. These unreported accidents pose a limitation on the data and may introduce information bias. Because police records are the only source for this study's essential information, the unknown error will have to be accepted.

The cities in this study not only present a wide variation in population, bikeway network density, road density and bicycle demand, but also in road hazards. San Francisco's downtown and mission district is a maze of rushing traffic with commuters scurrying to get home from work. Berkeley's University campus is home to more than 30,000 students and faculty members; having a concentrated number of bicyclists in such a small area provides a factor that may not match the other cities. By weighting each city's accident data using the ratios, mentioned in the "methods" section, I hoped to reduce these confounding factors as much as possible when comparing among cities. For comparisons where all city data was pooled, the problem of differing city communities was greatly reduced. This data only needed to be controlled for bikeway to road ratios. It is the total length of bikeways in a city that may ultimately affect whether an accident occurs on one or not. Unfortunately I could not control for potential confounders such as speed, miles ridden, weather and road conditions.

Statistical Methods *Contingency Table vs. MANOVA*. Because a multiple analysis of variance (MANOVA) model would not be sufficient (*n* is too small, and it is not the mean values that this study is testing), the contingency table was the approach to looking at all the variables at once. By using the contingency table, some contingency bias may have been introduced. As a general rule, no expected frequencies should be less than a value of 5. However, roughly half of my expected values fell below 1. But, it has been proven that this test is surprisingly robust when testing for uniform distribution, thus the low expected values were accepted.

Linear Regression vs. Linear Correlation. Correlations do not imply a cause and effect relationship, regressions do. The nature of the question asked in this analysis is if more bikeways directly affect fewer accidents. It is not asking if there *is* a relationship, but rather what the relationship is. One of the assumptions of regression analysis is that measurements of X

(%bikeway length the road length) be obtained without error. This is typically impossible, therefore this study assumes that the errors are negligible, or at least small compared to the Y (the accident rate) values. Regression statistics are known to be robust.

Chi-squared vs. t-test. Generally, *t*-tests are known to be much more robust than χ^2. However, because *t*-tests evaluate the difference in means between two groups, this test cannot be used for the analyses.

Conclusion Bicycle safety is not merely affected by the presence of a bike lane, path or route. Certain aspects that these bikeways create have shown an increase in some areas of bicycle safety and a decrease in others. Findings suggest that more bikeways within the cities transportation system may actually *increase* the overall rate of bicycle-motor vehicle collisions and interestingly, *increase* the rate of intersection accident where these bikeways exist.

The goal of bicycle safety advocates and coalitions should be to balance resources and allocate money equally among all bicycle safety areas: equipment, education, and facilities. The focus then should not primarily be on building more bikeways, but on how to safely travel on the existing bikeways. While improved engineering may help to increase bicycle safety, it does not take the place of learning how to bike with cars. Risks do not disappear simply because a bikeway is installed.

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References:

AASHTO, American Association of State Highway and Transportation Officials. 1999. Guide for the development of bicycle facilities. Prepared by the AASHTO task force on geometric design. Washington, DC, pp.1-12

Allen-Munley, C., and J. Daniel. "Urban Bicycle Route Safety Rating Model Application in Jersey City, New Jersey." Journal of Transportation Engineering. 132.6. 2006. pp. 499-507.

Allen-Munley, C., J. Daniel, and S. Dhar. Logistic Model for Rating Urban Bicycle Route Safety. Pedestrians and Bicycles; Developing Countries. Transportation Research

Record. Washington: Transportation Research Board National Research Council, 2004. pp. 107-15.

Allen, J. S. Consultant and expert witness in bicycle accident lawsuits. A Realistic Look at Bicycle Facilities, Laws and Programs. http://www.bikexprt.com/bikepol/index.htm. Assessed April 2007.

Aultman-Hall, L., and J. LaMondia. Evaluating the Safety of Shared-Use Paths - Results from Three Corridors in Connecticut. Bicycles and Pedestrians; Developing Countries 2005. Transportation Research Record. Washington: Transportation Research Board National Research Council, 2005. pp. 99-106.

Barnes, G., and K. Krizek. Estimating Bicycling Demand. Bicycles and Pedestrians; Developing Countries 2005. Transportation Research Record. Washington: Transportation Research Board National Research Council, 2005. pp. 45-51

Census 2000 Surface Transportation Policy Project. U.S. Department of Transportation. http://www.dot.ca.gov/hq/tpp/offices/bike/Appendix._F_Bike-Ped_Data.pdf#xml=http://dap1.dot.ca.gov/cgi-bin/texis/webinator/search/pdfhi.txt?query=pedestrian+and+bicycle&db=db&pr=www&prox=page&rorder=500&rprox=500&rdfreq=500&rwfreq=500&rlead=500&sufs=0&order=r&cq=&id=453969e57. Assessed Oct. 2006.

Dill, J., and T. Carr. Bicycle Commuting and Facilities in Major Us Cities - If You Build Them, Commuters Will Use Them. Pedestrians and Bicycles 2003. Transportation Research Record. Washington: Transportation Research Board National Research Council, 2003. 116-23.

FHWA, U.S. Department of Transportation. Bicycle and Pedestrian Provisions Summary, 2006. http://www.fhwa.dot.gov/environment/bikeped/bp-broch.htm. Assessed Oct. 2006.

Houten, R.V., and C. Seiderman. How Pavement Markings Influence Bicycle and Motor Vehicle Positioning. Transportation Research Record: Journal of the Transportation Research Board, No. 193, 9 TRB, National Academics, Washington D.C., 2005, pp3-14

Khan, A.M., A. Bacchus, and J.H. Allen. Bicycle Use of Highway Shoulders. In Transportation Research Record 1639, TRB, National Research Council, Washington D.C., 1995, pp. 8-21

NHTSA, U.S. Department of Transportation, National Highway Traffic Safety Administration. 1999 Motor Vehicle Crash Data from FARS and GES. Washington, D.C.: National Highway Traffic Safety Administration

No authors listed. Injury-control recommendations: bicycle helmets. Morbid Mortal Weekly Rep (MMWR), 1995; 44(RR-1): 1-17.

Traffic Safety Facts 2005 Pedalcyclists. NHTSA, U.S. Department of Transportation 2005

Wilkinson, W.C., et al. The Effects of Bicycle Accommodations on Bicycle/Motor Vehicle Safety and Traffic Operations. FHWA Report. 1992.

Zar, J. H.1999. Biostatistical Analysis. Prentice-Hall, Inc., New Jersey. 663 pp.