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Evaluation of Lane Reduction "Road Diet" Measures on Crashes and Injuries

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"Road diets" are often conversions of four-lane undivided roads into three lanes (two through lanes plus a center turn lane). The fourth lane may be converted to bicycle lanes, sidewalks, or on-street parking. Road diets are sometimes implemented with the objective of reducing vehicle speeds as well as the number of motor vehicle crashes and injuries. A study was conducted to investigate the actual effects of road diets on motor vehicle crashes and injuries. Twelve road diets and 25 comparison sites in California and Washington cities were analyzed. Crash data were obtained for these road diet (2,068 crashes) and comparison sites (8,556 crashes). A "before" and "after" analysis using a "yoked comparison" study design found that the percent of road diet crashes occurring during the "after" period was about 6% lower than that of the matched comparison sites. However, a separate analysis in which a negative binomial model was used to control for possible differential changes in average daily traffic, study period, and other factors indicated no significant treatment effect. Crash severity was virtually the same at road diets and comparison sites. There were some differences in crash type distributions between road diets and comparison sites, but not between the "before" and "after" periods. Conversion to a road diet should be made on a case-by-case basis in which traffic flow, vehicle capacity, and safety are all considered. It is also recommended that the effects of road diets be further evaluated under a variety of traffic and roadway conditions.

Continued growth and decentralization throughout the United States has increased the number of cars on both residential and arterial streets. As a result, some cities in the United States have reduced the number of travel lanes on some of their arterial and collector streets. These conversions commonly involve restriping four-lane undivided roads as three lanes (two through lanes plus a two-way left-turn lane). The fourth lane may be converted to bicycle lanes, sidewalks, and/or on-street parking. In other words, the existing cross-section is reallocated. These lane-reduction conversions are often called "road diets" (Figures 1 and 2). A few road diets are conversions from four-lane roads into two-lane roads, by restriping and/or by adding landscaped median islands. According to Burden and Lagerwey (*1*), four-lane roads with average daily traffic (ADT) of up to 25,000 have been converted to road diets.

Road diets can potentially offer benefits to both vehicles and pedestrians. On a four-lane street, drivers change lanes to pass slower vehicles (e.g., vehicles stopped in the left lane waiting to make a left turn). By comparison, on a two-lane street, drivers' speeds are limited by the speed of the lead vehicle. Thus road diets may reduce vehicle speeds and vehicle interactions during lane changes, which could potentially reduce the number and severity of vehicle-to-vehicle crashes. Road diets may also benefit pedestrians, because they will have two lanes of traffic (instead of four) to cross and motor vehicle speeds are likely to be lower. Recent research by Zegeer et al. (*2*) on crosswalk safety found a reduction in pedestrian crash risk for two- and three-lane roads, compared to roads with four or more lanes. Bicyclists may also benefit, especially when bicycle lanes are added (*3*).

Road diets may result in lower vehicle capacity compared to four-lane streets. However, on a four-lane street, the left lane is often utilized as a left-turn lane. With high levels of oncoming traffic, left-turning motorists who are waiting for an adequate gap will cause considerable delay to through traffic. Therefore, the four-lane street will have less capacity than it could potentially have. Under most ADT conditions tested, road diets have minimal effects on vehicle capacity, because left-turning vehicles are moved into a common two-way left-turn lane (*1, 4*). However, for ADTs above approximately 20,000 on road diet sections, there is an increased likelihood that traffic congestion will increase to the point of diverting traffic to alternate routes.

The purpose of this paper is to investigate the actual effects of road diets on motor vehicle crashes and injuries.

PAST RESEARCH

This section summarizes case studies of road diets in U.S. and Canadian cities.

California

Knapp et al. evaluated two road diets in California (*5*). High Street in Oakland had an ADT of 22,000 to 24,000. After High Street was converted from four to three lanes, the number of crashes decreased from an annual average of 81 before the conversion to 68 in the 1 year after. The total number of crashes fell by 52% after East 14th Street in San Leandro was converted.

The conversion of Valencia Street in San Francisco reduced the ADT by 10%, to 19,979 (*6*). The ADTs on four parallel streets increased by 2% to 8%. The total number of crashes per year decreased from 73.2 to 62, and injury crashes per year fell from 58.8 to 50. The number of bicycles during the p.m. peak hour more than doubled, from 88 to 215. Bicycle crashes per year increased from 10.1 to 12.

Also in San Francisco, Polk Street was restriped from three lanes to two lanes (*7*). Bike lanes were added to the southern segment. After the conversion, the ADT fell by 2%, to 16,300. The number of bicycles during the a.m. peak hour increased from 37 to 52. The ADTs on two parallel streets increased by 8% and 15%. Insufficient crash data were available for analysis.

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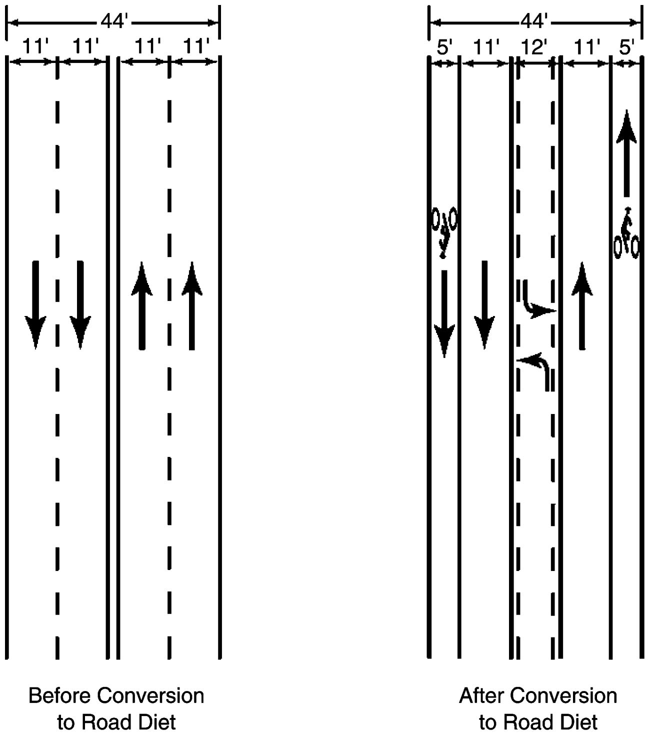

FIGURE 1 Representative road diet.

Iowa

A road diet on U.S. Highway 75 in Sioux Center resulted in a speed reduction of 2.7 km/h (1.7 mph) (*4*).

Michigan

In East Lansing, Burcham Road and Grand River Boulevard were converted. Burcham Road had four lanes and an ADT of 11,000 to 14,000, whereas Grand River Boulevard had four lanes and an ADT of 23,000. Both roads now have three lanes and new bicycle lanes (*1*).

Minnesota

Rice Street was converted from four lanes to three lanes, resulting in 33% fewer injury crashes (*8*).

Montana

For the road diet on 17th Street West in Billings, Montana, the total number of crashes in the "after" period was 62% lower than the number in the "before" period (*4*).

Ontario, Canada

St. George Street in Toronto passes through the University of Toronto campus. It previously operated as a four-lane road during peak periods and had an ADT of 15,000. In 1993, it was reconfigured to include bicycle lanes on both sides, a narrow painted median, and two travel lanes. Three years later, the street was narrowed from 14 m (46 ft) to 11 m (36 ft), with the extra right-of-way going to a wider sidewalk (*9*). Also in Toronto, a six-lane section of Davenport Road with an ADT of 30,000 was narrowed to four lanes in 1994. Bicycle lanes and parking were added on both sides (*9*).

Pennsylvania

A 1-mi section of Electric Avenue in Lewistown, Pennsylvania, was converted from four lanes to three lanes. The ADT was 13,000. Most local residents were initially opposed because they thought that their trip times would increase. Instead, it was found that overall trip times were unaffected. The number of crashes dropped to nearly zero (*1*).

Washington State

Lake Washington Boulevard in Kirkland formerly had four lanes and an ADT of 20,000. The multiple lanes of heavy traffic flow made it difficult for residents to find sufficient gaps to enter and exit their driveways. The boulevard was restriped with three lanes. As a result, speeding and noise levels were reduced. Moreover, residents had an easier time entering and exiting their driveways (*1*).

Seattle's first road diet dates back to 1972. Starting in 1991, more streets were converted. Burden and Lagerwey examined crash data for selected intersections and midblock sections along nine road diets. The "before" and "after" time periods were generally 3 years each. There was a 34.1% reduction in total crashes and a 7.4% drop in injury crashes in the "after" period, compared to the "before" period (*1*).

Summary of Past Research

Some of the case studies reviewed in this section included comparisons of the number of crashes before and after the conversion to a road diet. These comparisons have shown that road diets can reduce the total number and severity of crashes. However, some of these studies had certain limitations. First, only selected intersections and midblock sections were sometimes evaluated, instead of the entire road diet section. Second, no comparisons with non-road diet locations were made in any of the studies cited above. The observed reduction in crashes, therefore, could have been a citywide phenomenon (such as a reduction in crash reporting) and not necessarily the result of installing road diets.

A more extensive study is needed to investigate further the effects of road diet conversions on safety. Such a study would use detailed crash data from before and after the conversion to a road diet and would also compare road diets with similar streets that were not converted. This paper describes such a detailed investigation of crashes on road diet conversions in two states.

STUDY METHODOLOGY

Selected Sites

This study evaluated road diets at locations in several California and Washington cities that had installed road diets. These two states were selected for two reasons. First, it was learned that several cities

(a) (b) (c) (d)

FIGURE 2 Examples of road diets.

in California and Washington had installed road diets. Second, both states are part of FHWA's Highway Safety Information System. Therefore, it was felt that the necessary high-quality crash data for a large number of crash, roadway, and vehicle variables would be available for study.

Research Designs

A four-group study design was utilized: a treatment and a comparison group were selected, and data were obtained for two time periods, one "before" the treatment was installed and one "after" installation for each site in each group. More specifically, the road diets (i.e., treatment sites) were matched with four-lane streets that were otherwise similar (i.e., comparison sites). Thus crash data were obtained for four groups: (*a*) road diets—"before" period, (*b*) road diets—"after" period, (*c*) comparison sites—"before" period, and (*d*) comparison sites—"after" period.

The data were analyzed using two different methods: (*a*) a site-by-site analysis in what is referred to as a "yoked comparison" design (since each treatment site had one or more matched comparison sites); and (*b*) a comparison site analysis, in which all treatment and comparison sites are essentially combined into two groups for each time period, and a negative binomial model of crashes per mile is developed such that the treatment effect can be examined while controlling for other variables such as ADT, city, and length of study period.

Most comparison sites were four-lane undivided roads that were near the road diets (such as a parallel road one or two blocks away or a road perpendicular to the road diet). A few comparison sites were unconverted (i.e., four-lane undivided) sections of the same road beyond where the road diet was installed. The comparison sites were selected to be similar to the road diets in terms of roadway functional class, type of development (e.g., commercial or residential), speed limit, intersection spacing, and access control.

Many streets, especially in Seattle, had cross sections that were wide enough for four lanes [13.4 m (44 ft)] but were only striped for two lanes. That is, the streets had 6.7-m (22-ft) lanes. The lanes accommodated both through traffic and on-street parking. These streets were not selected as comparison sites because these streets would operate as two-lane streets when vehicles were parked along the curb.

It was thought that the road diets could possibly prompt some motorists to divert onto nearby four-lane roads (including comparison sites) so as to avoid the slower road diet route. These comparison sites were considered to be "nearby comparison sites" because motorists who wanted to use alternate routes could travel along the nearby comparison sites instead. The additional traffic could possibly influence the number, types, and severity of crashes at the nearby comparison site.

On the other hand, "faraway comparison sites" were comparison sites that were in other areas of the city and would not be candidates for motorists to use as an alternate route to avoid a road diet section. Any increases in ADTs at faraway comparison sites were presumed to result from other factors and not the installation of road diets.

Site Selection

Local traffic engineers in California and Washington were contacted to determine where road diets were located. Road diets were identified in eight cities: Bellevue (Washington), Mountain View (California), Oakland (California), Sacramento (California), San Francisco (California), San Leandro (California), Seattle (Washington), and Sunnyvale (California). The reader is advised that these are not the only cities in California and Washington that have road diets.

Candidate comparison sites were identified through a review of maps and discussions with local traffic engineers. Field visits to the eight cities were made to verify that the candidate comparison sites were suitable. Subsequently, one or more nearby comparison sites was selected for each road diet. Faraway comparison sites were also selected, but suitable faraway comparison sites could not be found for every road diet. Some road diets were rejected because they were installed before 1990 or because a suitable nearby comparison site could not be found.

The final list of sites contained 30 road diets and 50 total matching comparison sites in eight cities. (As noted below, 12 road diets and 25 comparison sites are included in this paper.) The road diets ranged in length from 0.13 km (0.08 mi) to 4.09 km (2.54 mi). The comparison sites ranged in length from 0.21 km (0.13 mi) to 4.88 km (3.03 mi). Local traffic engineers did not have complete "before" and "after" ADT data for every road diet and comparison site. At a few locations, the ADTs were of questionable accuracy, perhaps due to irregularities in how the ADTs were obtained.

Crash Variables

Local traffic engineers provided crash data for the road diets and comparison sites. The crash data were not hard-copy police crash reports, but rather computer-generated summary lists of crashes and their characteristics.

The following crash variables were used in the analyses that are reported in this paper:

1. Date of crash (day, month, and year);
2. Crash type (angle/turning, head-on, rear-end, sideswipe, etc.);
3. Number of injuries; and
4. Number of fatalities.

Crash Data Periods

In this study, a 3-month transition period was defined: the month before road diet installation, the month of installation, and the month after installation. The transition period was defined for two reasons: (*a*) work on the road diet may have started the month before, and (*b*) motorists need some time to become familiar with the new traffic patterns of the road diet. The transition period separates the "before" period from the "after" period. Crashes that occurred during the 3-month transition period were excluded from the analysis.

Three years (36 months) of "before" and 3 years of "after" data were considered desirable for each road diet and comparison site. The actual amount of data varied considerably from site to site, depending on how much data the city had available, and when the road diet was installed. At most locations, one or more years of data were obtained for each of the "before" and "after" periods. Because all four seasons were represented, seasonal variations in crashes caused by weather conditions were accounted for.

Data Coding

The values for each crash variable were obtained from the crash summaries and keyed into a database. Each record in the database is a specific crash and contains the name of the street where the crash occurred, location type (road diet, transition, nearby comparison, or faraway comparison), whether the crash occurred before or after the road diet was installed, and the values for each crash variable.

The intersections at either end of a road diet are locations where motorists are entering and exiting (i.e., transitioning in and out of) the road diet. At these intersections, motorists may be switching lanes or adjusting their speeds in response to different operational conditions downstream. Hence the intersections at either end of a road diet were regarded as "transition" areas and were excluded from the analysis.

Where one section of a street was a road diet and an adjacent section of the same street was a nearby comparison site, the intersection separating the road diet from the comparison site was regarded as a transition area. The section of the nearby comparison site immediately adjoining the road diet was regarded as a buffer area, defined as extending one average city block (about 91 m or 300 ft) from the transition area. Crashes occurring in the buffer area were also excluded from the analysis.

ANALYSIS

As mentioned above, crash data were initially obtained for 30 road diets and 50 comparison sites. However, many locations had small sample sizes of crashes because of short segment lengths, short data periods, or low ADTs. Therefore, a subset of 12 road diets (2,068 crashes) and 25 comparison sites (8,556 crashes) was chosen for the analyses that are reported in this paper. These locations generally had segment lengths of at least 0.81 km (0.50 mi). The road diets and comparison sites were placed into 11 groups, each consisting of one or two road diets and their matching comparison site(s). The road diets and comparison sites in each group were located in the same city, thereby accounting for possible differences in crash reporting practices among cities. Preliminary crash analyses revealed that nearby and faraway comparison sites were similar, so the nearby and faraway comparison sites in each group were combined for the analyses that are reported in this paper.

Before the basic analyses were conducted, changes in the road diet and comparison site ADTs were examined to determine whether motorists were diverting off road diets and onto nearby comparison sites. ADT data for the years immediately before and after road diet installation were available for four road diets, five matching nearby comparison sites, and four matching faraway comparison sites. For example, if the road diet was installed in August 1995, then ADT data were available for 1994 and 1996 (the years before and after installation, respectively). The "before" period ADTs on the road diets ranged from 10,179 and 16,070; on the nearby comparison sites, 14,003 and 17,000; and on the faraway comparison sites, 5,480 and 22,600. A comparison of the ADTs found that, on average, the ADTs on the four road diets increased by 6.4%. A slightly higher increase of 9.4% occurred on the five nearby comparison sites. The ADTs on the four faraway comparison sites increased by 6.7%. For the sites included in this analysis, any diversionary effect of road diets is limited. Instead, the dominant phenomenon is an overall increase in ADT, the result of population growth and other factors.

The crash-related analyses were divided into five categories:

1. Crash trends in the "before" period to determine the validity of the comparison sites,
2. "Before" and "after" crashes at individual groups of treatment/comparison sites,
3. Analyses involving crashes as a function of traffic volumes,
4. Crash severity, and
5. Crash types.

FINDINGS

Crash Trends in "Before" Period

Year-by-year crash trends in the "before" period were examined for all 11 groups of road diets and comparison sites. The objective was to see whether the comparison sites were a good match with the treatment sites in terms of having similar crash trends.

Crash data were available for the same years for all sites within a group. Because the road diets were installed over a period of several years, the "before" intervals differed considerably from site to site. Within most groups, the road diet and comparison sites had quite parallel trends in crashes per month. Crashes per month were plotted instead of crash rates, because ADTs were not always available. A sample plot is shown in Figure 3.

The proportion of crashes that occurred at road diet sites among all crashes occurring at either road diet or comparison sites was then examined, on a year-by-year basis. Trends in these proportions would indicate that crashes at road diets and comparison sites were not following parallel trends. To provide an estimate and test of significance of a trend component, logistic regression models were fit to three groups of sites with a total of four road diets and seven comparison sites (Groups 2, 9, and 11 in Table 1). These groups had five or more years of "before" data.

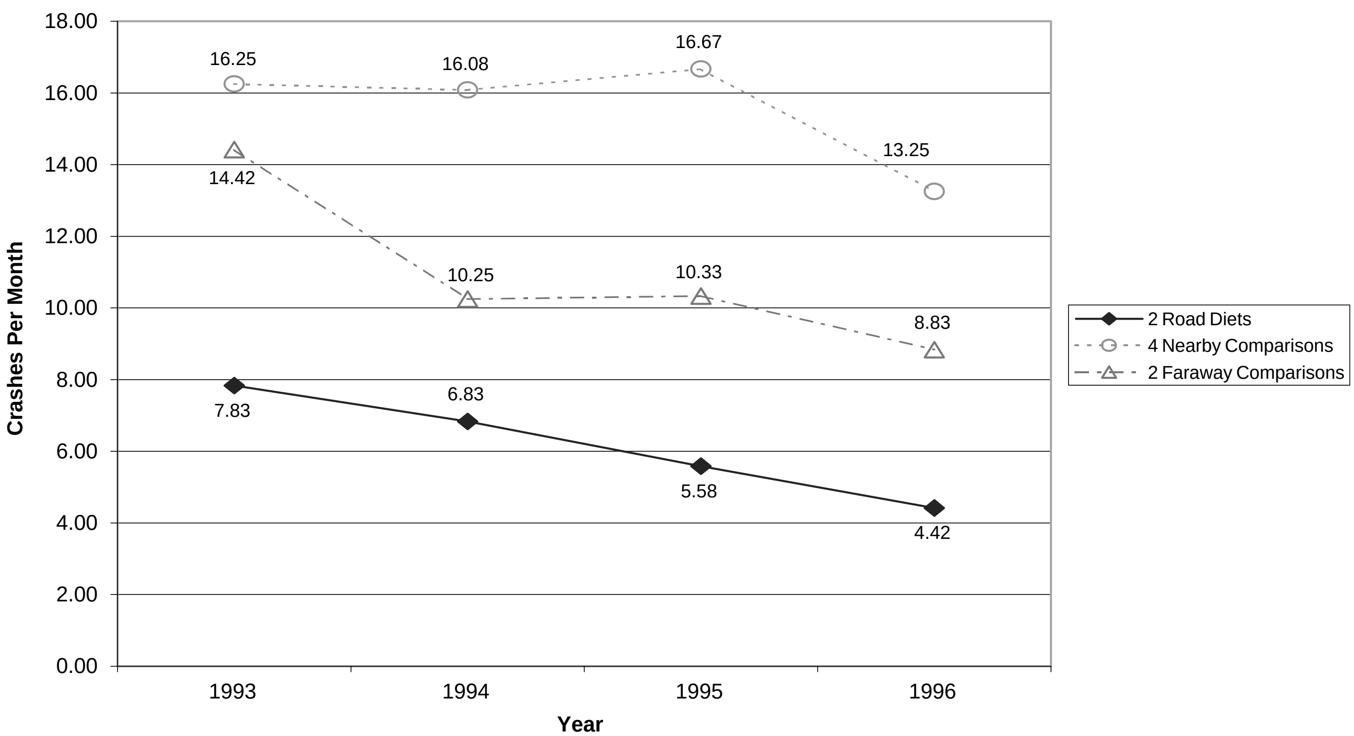

FIGURE 3 Crashes per month on road diets and comparison sites in Oakland.

The trend components were not statistically significant (p = .2815, .6131, and .1196, respectively). In other words, there were no significant differences in crash trends between the road diet sites and their matching comparison sites. For the sites in other cities, the proportions were not consistently increasing or decreasing over the years for which "before" data were available. To summarize, it does not appear that crashes at the comparison sites behaved very differently over time from those at the road diet sites in the "before" period. Thus, it was concluded that the comparison sites were a good match to the road diet sites.

"Before" and "After" Crashes

Using standard yoked comparison analysis techniques, a three-way contingency table analysis was done using 10 groups, with 11 road diets and 24 matching comparison sites. Table 1 shows before-and-after crash frequencies (i.e., total number of crashes) and the percent occurring in the "after" period for road diets and comparison sites within each group. In all 10 groups, the percent of road diet crashes occurring in the "after" period was the same or lower than the corresponding percent for the comparison sites. In four groups, this difference was at least marginally statistically significant.

When data from all 10 groups are pooled, a somewhat higher percent of crashes at the comparison sites occurred in the "after" period than at the road diet sites (41.0% versus 35.8%). Crash frequencies were generally higher at comparison sites than at road diet sites. A Cochran–Mantel–Haenszel test of overall significance across the 10 groups was statistically significant ($\chi^2_{1df} = 7.5307$, $p = .0061$) (df = degrees of freedom). The estimated risk ratio indicates that the percent of crashes at road diet sites in the "after" period to be about 6% less likely than a crash at a comparison site, with 95%

TABLE 1 "Before" and "After" Crashes at 10 Groups of Road Diets and Matched Comparison Sites

Group Number	Site Type[a]	Months of Data		Crashes		Percent		P-value
		Before	After	Before	After	After	χ^2_{1df}	
1	R	40	106	63	164	72.3	.009	.9255
1	C	40	106	347	917	72.6		
2	R	91	25	102	32	23.9	.039	.8444
2	C	91	26	231	76	24.8		
3[b]								
4	R	56	56	82	74	47.4	.014	.9048
4	C	56	56	583	537	48.0		
5	R	35	75	152	252	62.4	2.995	.0835
5	C	35	75	95	208	68.7		
6	R	50	60	85	97	53.0	.538	.4632
6	C	50	60	793	1005	55.8		
7	R	74	19	44	8	15.4	.015	.9030
7	C	74	19	188	36	16.1		
8	R	42	48	16	4	20.0	8.275	.0040
8	C	42	48	61	73	54.5		
9	R	66	12	255	28	9.9	3.479	.0621
9	C	66	12	661	110	14.3		
10	R	53	25	121	39	24.4	4.180	.0409
10	C	53	25	877	419	32.3		
11	R	61	8	407	43	9.6	.002	.9610
11	C	61	8	1210	129	9.6		
Total	R			1327	741	35.8	[c]	[c]
Total	C			5045	3510	41.0		

NOTE: *Risk of Crash in After Period at Road Diet Site Relative to Comparison Site: Risk Ratio = .944, 95% confidence limits for risk ratio = .894, .997.*

[a] *R = Road diet, C = Comparison site*

[b] *The road diet in Group 3 consisted of two sections with different "before" and "after" periods, so this group was excluded from the before-and-after analysis.*

[c] *Overall test of association: $\chi^2_{1df} = 7.5307$, p = .0061.*

confidence limits of .003 and .106. Thus, on average, crash frequencies at road diets in the "after" period were approximately 6% lower than at the corresponding comparison sites.

ADTs generally increased on road diets and comparison sites, but there was no clear pattern as to whether road diets or comparison sites had greater increases. Before-and-after data on speed variance, turning queues, and other traffic flow characteristics were not available. Further research is needed to find out whether the crash reductions observed on road diets can be attributed to lower speeds, fewer conflicts, or possibly other factors.

Analyses Involving Crashes as a Function of Traffic Volumes

The before-and-after analysis described above was based solely on crash counts and did not require ADT data. For those sites that had reliable ADT data, it was possible to analyze crashes further as a function of ADT at road diets and comparison sites in the "before" and "after" time periods. ADT data were not available for sites in Oakland or San Francisco, so three of the groups from the before-and-after analysis were excluded from the crash rate analysis. However, a group of sites in Seattle that was not used in the before-and-after analysis because of differing "before" and "after" time periods for the road diets and comparison sites was included. Thus these current analyses included 8 groups, with 8 road diets and 14 comparison sites. The ADTs on the road diets ranged from 8,133 to 15,658 in the "before" period and from 8,300 to 16,482 in the "after" period. The ADTs on the comparison sites ranged from 5,480 to 24,183 in the "before" period and from 7,006 to 26,100 in the "after" period.

In this set of analyses, raw crash rates were first examined to see if meaningful findings might emerge. Here, crashes, ADT, and study period length were combined to calculate a crash rate per million vehicle miles of travel for each site in both the "before" and "after" periods. Figure 4 shows the distributions of these crash rates for road diets and comparison sites in the "before" and "after" periods. The boxes extend from the 25th to the 75th percentiles of the distributions, whereas the vertical lines extend to the extreme values of the distributions. The horizontal lines across the boxes show the median values. The "+" signs represent the means of the distributions. This figure shows that the distributions of crash rates at the road diets are less variable than those at the comparison sites. The mean crash rates at the road diets are slightly lower than at the comparison sites. The means decrease (slightly) from the "before" period to the "after" period at both road diets and comparison sites, but not differentially.

While these raw crash rates are somewhat useful, as noted by Hauer (*10*) and others, an examination of rates such as these cannot control for the effect of volume changes across time, and can result in somewhat misleading results. For this reason, the primary analyses of crashes as a function of traffic volume were carried out by fitting negative binomial regression models to the crash frequencies at each site, and using ADT and other factors as independent variables. The negative binomial model is a form of a generalized linear model. In this application, crash frequencies y_j at sites $j = 1, \ldots, N$ are assumed to follow a negative binomial distribution. It is further assumed that the log transform of the expected value of y_j can be modeled as a linear function of the explanatory variables. Thus the model has the form

$$\log[E(y_i)] = \beta_0 + \beta_1 X_{1j} + \cdots + \beta_{kj}$$

The model parameters $\beta_0, \beta_1, \ldots, \beta_k$ are estimated by maximum likelihood.

The explanatory variables were traffic volume (millions of vehicles), city or alternatively group, site type (road diet or comparison site), time period (before or after), and a site type by time period interaction. Segment length was included as a constant factor (i.e., the number of crashes on a segment was proportional to its length). More information about negative binomial regression models can be found in McCullagh and Nelder (*11*).

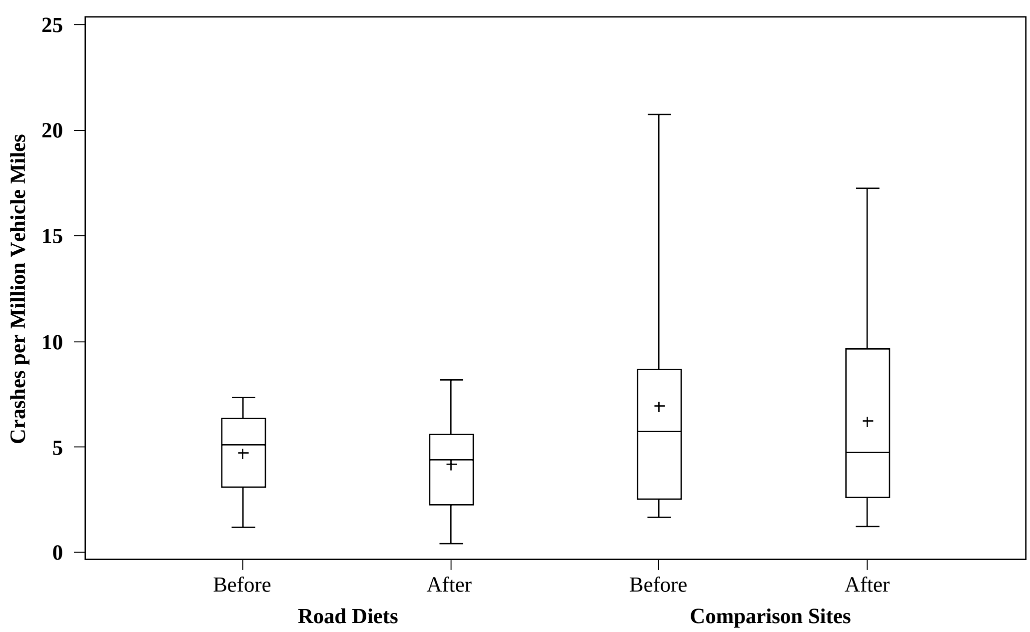

FIGURE 4 Crash rates per million vehicle miles.

Table 2 shows results from the final model. These results show highly significant variation in crash rates with traffic volume and city, and lesser variation with site type. The city-by-city variations are probably the result of different operational conditions and crash reporting practices. Neither the period effect nor the period by site type interaction was statistically significant. A significant interaction effect would have indicated that crash rates changed from the "before" period to the "after" period differently on road diets than on the comparison sites (and thus that the road diets had an effect on crashes while controlling for ADT and city).

Parameter estimates for site type, time period, and their interaction are also shown at the bottom of Table 2. These estimates show crash rates per mile to be somewhat higher on comparison sites relative to the road diet sites, to decrease slightly from the "before" to the "after" time period and to decrease somewhat less on comparison sites than on road diet sites. The last two estimates were not statistically significant, however, again indicating the lack of a road diet effect on crashes per mile.

Crash Severity

A crash was classified as property damage only (PDO) if no injuries and no fatalities occurred. Otherwise, it was classified as injury and fatal. It was expected that crashes on road diets would be less severe (i.e., a higher percentage of PDOs) in the "after" period, if motorists were indeed driving more slowly after the road diets were installed than when there were four-lane streets. However, no actual vehicle speed data were collected before and after the road diets were installed.

The severity analysis included 10 groups, with 10 road diets and 20 comparison sites. The total number of crashes was 7,919. San Francisco was excluded from this analysis because the majority of its crashes resulted in injuries and fatalities. Due to local reporting practices, many PDO crashes are not reported. The effects of changing reporting thresholds are discussed in Zegeer et al. (*12*). In this analysis, the "after" period in Seattle extended through December 31, 1996 only, because the number of injuries and fatalities was not available for crashes occurring on January 1, 1997 or later.

Overall, approximately 63% (5,007) of the crashes resulted in no injuries or fatalities. The remaining 37% (2,912) of the crashes had at least one injury or fatality. These percentages were quite similar for both road diet and comparison sites, and in both the "before" and "after" time periods. Injury rates did, however, tend to vary somewhat from city to city and among the matched groups of sites. To take this variation into account, a logistic regression model was fit to the injury severity data (coded as no injury versus injury or fatality). Logistic regression is another form of a generalized linear model. In this case, the injury classification variable (yes or no) is taken to be a Bernoulli random variable with a mean value (or proportion injured at site j) of p_j. The logit transform of p_j, $\log [p_j / (1 - p_j)]$, is then modeled as a linear function of the explanatory variables, and the parameters are estimated by the method of maximum likelihood. The explanatory variables in the model were: (*a*) matched group (1 to 11), (*b*) site type (road diet or comparison), (*c*) time period (before or after), and (*d*) site type by time period interaction. McCullagh and Nelder provide a fuller explanation of logistic regression models (*11*).

The crash severity model found that group was the only significant factor ($\chi^2_{9\text{df}} = 347.69$, $p < .0001$). Crash severity was virtually the same at road diets and comparison sites and did not change from the "before" to the "after" time period. The city-by-city variations are most likely the result of different crash reporting practices in each city.

It was thought that injury and fatal crashes would decrease on road diets relative to comparison sites, assuming lower vehicle speeds on road diets in the "after" period. Perhaps speeds did not decrease on the road diets included in this study. However, before-and-after speed data were not available, so it cannot be determined what

TABLE 2 Crash Rate Model: Likelihood Ratio Statistics and Parameter Estimates

Likelihood Ratio Statistics			
Source	df	χ^2	P-value
Traffic Volume	1	18.34	<.0001
City	3	44.90	<.0001
Time Period	1	2.01	.1564
Site Type	1	8.11	.0044
Period X Type	1	.40	.5278
Parameter Estimates			
Parameter	Estimate	95% Confidence Limits (Lower, Upper)	P-value
Comparison Site vs. Road Diet	.34	-.04, .73	.0794
After vs. Before	-.28	-.73, .17	.2267
Comparison Site in "After" Period	.17	-.36, .70	.5337

NOTE: df = degrees of freedom.

happened to vehicle speeds. Also, the crash summaries only listed the number of injuries and fatalities in each crash. None of the summaries categorized the injuries as an "A" (incapacitating), "B" (nonincapacitating), or "C" (possible) injury. It is possible that road diets could have resulted in fewer A injuries (and more B and C injuries) compared to comparison sites. Such a result would not be apparent in an analysis of PDO versus injury and fatal crashes.

Crash Types

Another question of interest concerned whether or not crash types would be different after road diets were in place relative to comparison sites. The three most prevalent crash types at all sites were angle, rear-end, and sideswipe (Figure 5). While the crash type distributions were quite similar for the site type by period interaction, angle collisions were somewhat higher for the road diets and perhaps decreased somewhat less in the "after" period relative to the comparison sites. To investigate this, a logistic regression model was fit to a crash type variable (angle versus all other) using the same explanatory variables as the crash severity model. The results from this model again indicated a highly significant effect due to group ($\chi^2_{9\text{df}} = 199.24$, $p < .0001$). Site type was also statistically significant ($\chi^2_{1\text{df}} = 13.24$, $p = .0003$), with the proportion of angle collisions higher on road diets than on comparison sites. Neither time period nor the period by site type interaction was significant ($p = .5862$ and $p = .9575$, respectively).

A similar model showed the proportion of rear-end crashes to be higher for the comparison sites, again with no significant interaction or period effects. The only significant effect in a model for sideswipe crashes was that due to group.

It is not clear why the crash type distributions were different between the road diets and the comparison sites; crash severity was virtually the same at road diets and comparison sites. One possible reason is that such differences do exist from one roadway section to another because of variations in the numbers of driveways and intersections, vehicle speeds, vehicle mix, area type, and other factors. It may be that cities selected roadway sections for road diet installation at least partly because of such factors.

The variations in the crash type distributions among cities are likely the result of (*a*) how each city classifies crashes, and (*b*) what each city's reporting practices are. For example, Bellevue has a separate crash type for "parked vehicle." Several other cities usually classify crashes involving parked vehicles as "sideswipe." As another example, all of the California cities included "angle/turning" crashes in the total number of "right angle" crashes. In Bellevue and Seattle, "angle/turning" and "right angle" crashes were two separate crash types.

Summary of Findings

The key findings of this study are summarized as follows and in Table 3.

1. The road diets and comparison sites had similar year-by-year trends in crash frequencies in the "before" period. This finding is evidence that the comparison sites were a good match with the road diets.

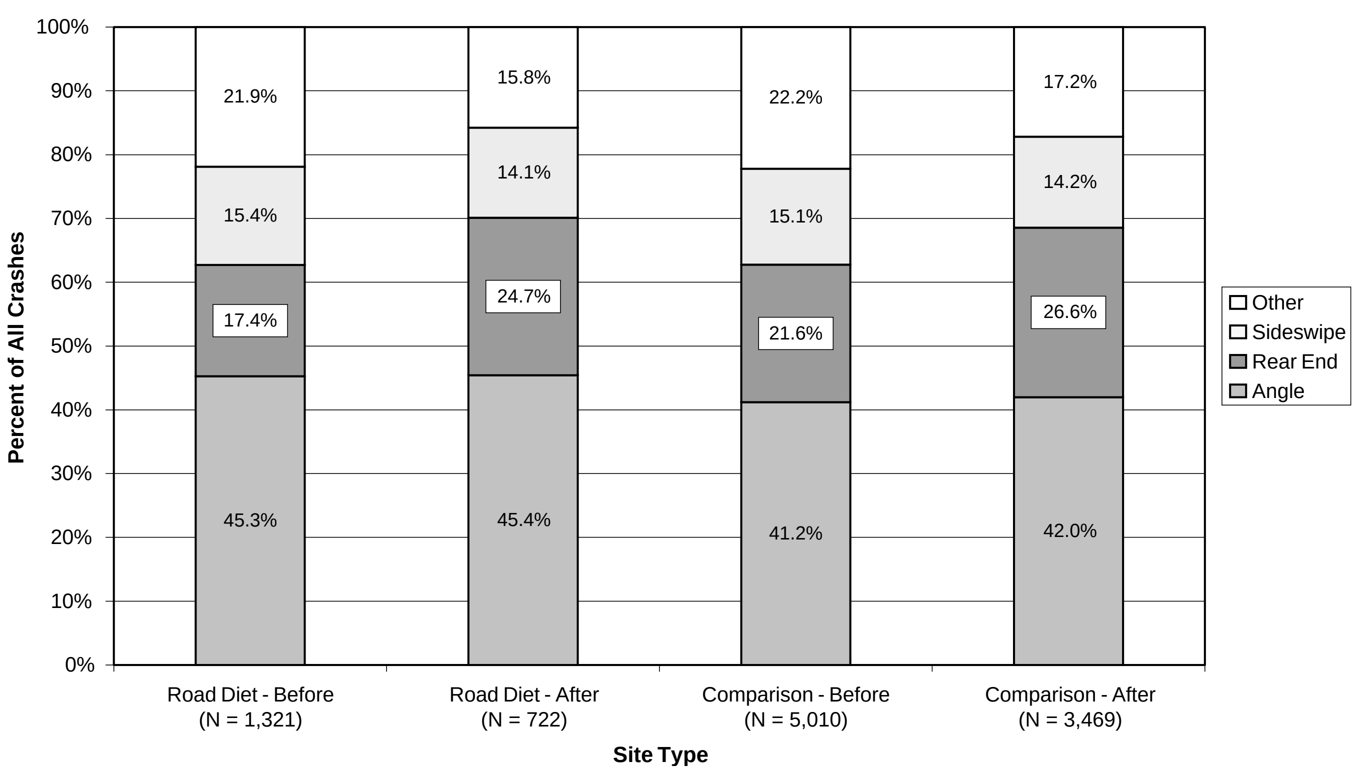

FIGURE 5 Distribution of crash types for road diet and comparison sites (N = number of crashes).

TABLE 3 Summary of Findings

Analysis Category	Comparison			
	Road Diets Before vs. After	Comparison Sites Before vs. After	"Before" Period Road Diets vs. Comparison Sites	"After" Period Road Diets vs. Comparison Sites
Crash Frequency	Reduction in "After" Period	No Change	No Difference	Road Diets Lower
Crash Rates	No Change	No Change	Road Diets Lower	Road Diets Lower
Crash Severity	No Change	No Change	No Difference	No Difference
Crash Type	No Change	No Change	Difference: 1. Road diets had a higher percentage of angle crashes 2. Road diets had a lower percentage of rear-end crashes	Difference: 1. Road diets had a higher percentage of angle crashes 2. Road diets had a lower percentage of rear-end crashes

2. Given the total number of crashes that occurred at the road diets and comparison sites, a higher percentage of the crashes at comparison sites (41.0%) occurred in the "after" period than at the road diets (35.8%) (Table 1). Crash frequencies at road diets in the "after" period were approximately 6% lower than at the corresponding comparison sites.

3. Crash rates did not change significantly from the "before" period to the "after" period. Crash rates were lower at road diets than at comparison sites, but road diets did not perform better or worse over time (from the "before" period to the "after" period) relative to comparison sites.

4. Road diet conversions did not affect crash severity. About 37% of the crashes resulted in an injury or fatality. The percentages were quite similar for road diets and comparison sites, and for both the "before" and "after" periods.

5. Road diet conversions did not result in a significant change in crash types. Three crash types—angle, rear-end, and sideswipe—accounted for about 80% of all crashes. Road diets had a somewhat higher percentage of angle collisions than the comparison sites had. On the other hand, the comparison sites had a higher percentage of rear-end collisions than the road diets had. Both differences were significant. However, the changes between the "before" and "after" periods were not significant.

CONCLUSIONS

Because there are no data available on a large reference group of similar sites in these cities (i.e., all these data were manually collected), this study could not be collected using the more robust before-and-after design involving empirical Bayes methods as proposed by Hauer (*10*). However, the previously discussed techniques did control for the most prevalent possible biases—different study periods for the groups and differential changes across time in ADT between the treatment and comparison groups. The former was controlled for in the initial yoked comparison analyses, and both were controlled for in the negative binomial modeling. It is also noted that the fact that the rates are higher for the comparison sites than for the treatment sites (as shown in Figure 4) is an indication that regression to the mean is probably less of a potential bias in this data set; the treatment sites do not appear to have been chosen solely because of high prior crash rates or frequencies. For these reasons, the authors believe that the study results are soundly based.

This study found that a significantly lower (approximately 6%) proportion of crashes occurred at road diets in the "after" period than at comparison sites in the "after" period. Thus one may expect that converting a roadway segment from four-lane undivided to three lanes would likely reduce total crashes by 6% or less. Road diets were no better or worse than comparison sites with regard to crash rates and severity. Further research is needed to find out whether the crash reductions observed on road diets can be attributed to lower speeds, fewer conflicts, or possibly other factors.

It was beyond the scope of this study to examine potential nonsafety benefits of road diets, such as creating the impression that cars are less dominant, enhancing the urban landscape, and improving the overall quality of life along the street. These nonsafety benefits should be evaluated more thoroughly in future research. It should be mentioned that traffic operations and capacity issues need to be considered fully at a given site prior to implementing road diets and other lane reduction measures.

Local traffic engineers should attempt to evaluate road diet conversions, whenever possible, in terms of safety and operational effects. In particular, it would be useful to conduct further studies of motor vehicle speeds, congestion, traffic volume, and traffic flow resulting from road diet conversions. Future operational studies under a range of traffic volumes and other conditions would be useful to help quantify the conditions for which road diets would be appropriate.

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