Pedestrian and Bicycle Information Center

White Paper Series

Road Diet Conversions: A Synthesis of Safety Research

May 2013

Libby Thomas, Senior Associate, UNC HSRC

For:
Federal Highway Administration
DTFH61-11-H-00024

This material is based upon work supported by the Federal Highway Administration under Cooperative Agreement No. DTFH610110H-00024. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the Author(s) and do not necessarily reflect the view of the Federal Highway Administration.

Summary

The primary purpose of this review is to assess the available evidence regarding the safety effectiveness of reductions in the number of motorized traffic lanes, widely known as road diet conversions. Although road diets have been implemented since at least the 1970s, earlier reviews and a search of the literature identified no controlled safety evaluation studies conducted prior to the year 2002. A systematic search of literature dating from 2002 was conducted. Six studies in total were initially identified, with four serving as the basis for most conclusions in this review. Several of the studies have used overlapping data from many of the same implementation sites, with the more recent studies employing the more robust study methodologies. As a result, the strongest evidence comes from relatively few studies building on earlier ones. However, a sizeable number of sites have been encompassed in the studies. Studies using data from sites in California, Iowa, and Washington provide the strongest evidence of safety effects, with additional reports providing corroborating, but somewhat weaker evidence.

Road diets can be seen as one of the transportation safety field's greatest success stories. Total crashes might be expected to decline by an average of29 percent by converting from four, undivided lanes to three lanes (plus other uses such as bike lanes). Additionally, the studies determined total crash reductions were higher (47 percent) for treated sections of more rural thoroughfares passing through smaller towns (Iowa sites) and lower (19 percent) for road diet corridors in large urban areas (California and Washington sites) (Harkey et al., 2008).

Thus far, only a single study from New York City has examined effects on pedestrian crashes (Chen et al., 2013). Although the researchers were unable to use the most robust methodology due to a lack of traffic volume data, the inclusion of 460 road diet sites and large number of comparison locations supports the findings of significant reductions in total crashes, significant reductions in injurious and fatal crashes, and a trend of lower pedestrian crashes at segments. Total crashes and injurious crashes also declined significantly at intersections abutting the road diet sections.

Each potential road diet should be vetted on a case by case basis. Case study and modeling results suggest that added caution is warranted before implementing road diets when volumes approach 1,700 vehicles per peak hour or are in the range of 20,000 to 24,000 vehicles per day (HSIS, 2010; Knapp and Giese, 2001; Welch, 1999). However, high quality disaggregate estimates of safety effects of road diets for different volume roadways are lacking. Further study of potential traffic and safety effects on surrounding roads and access from side streets to the road diet corridor may also be needed.

Introduction and Purpose of this Review

Road diets, also known as road conversions, are the reallocation of road space through reduction of the number of motorized traffic lanes. They are of interest to communities that may be seeking to smooth traffic flows and reduce traffic speeds, improve access management, reduce crashes, improve safety and accessibility for pedestrians or bicyclists, improve parking utilization, improve economic function of the street, or in general gain space for uses more compatible with the purposes of the street. Some streets that were built with peak flows in mind, or because the thinking at the time was that more lanes are better, may have excess capacity for most periods of the day, and roadway space that is not well-utilized. The intent of this review was to assess the available evidence regarding the safety effects of road diet conversions.

In addition to the safety effects, roadway managers are interested in knowing what traffic volume and roadway conditions are most amenable to treatment, while still providing adequate mobility. In general, road diets have been described as maintaining motor vehicle capacity for converted roads with average daily traffic volumes (AADTs) up to approximately 20,000 vehicles per day under most conditions tested. Road diets may also provide safety and mobility benefits to other modes of travel, including bicycling and walking (HSIS, 2010).

As mentioned, the reallocation of space can further goals for pedestrian safety and mobility. Even if the reallocated lane space is not used directly for pedestrian facilities, the use of space to add parking or bicycle lanes increases the buffer between motorized traffic and pedestrians walking along the sidewalk. Bike lanes may also add to the buffer between motorized traffic and fixed objects such as trees and street furniture along the roadside. The fewer number of motorized lanes associated with a four-lane to three-lane conversion, or two lanes with median, also reduces pedestrians' exposure to traffic when crossing streets. A center, two-way left turn lane (TWLTL), or median islands also provide space for pedestrian refuge. More capital-intensive conversions include curb realignments or the addition of center medians or median islands. If curbs are realigned, space may be allocated to green space or other buffers, or to increase sidewalk width.

The most commonly studied reallocations of space have been conversions of undivided, four-lane roads into three lanes (one through lane in each direction plus TWLTL), and typically involve reallocation through striping or re-channelization. Many conversions include the addition of dedicated bike lanes in both directions as part of the space reallocation, a change in parking space allocation, or the addition of both parking and bike lane space. Therefore, these types of road diets rely on relatively inexpensive re-striping, perhaps in association with re-paving. Such actions can be very cost-effective if combined with regular maintenance activity. Conversions may also incorporate signal timing or phasing changes at intersections to optimize operations and safety benefits. Some communities are also combining road diets with roundabout intersection designs.

Background on Safety and Operational Effects

Welch (1999), in a paper presented to the Transportation Research Board (TRB) and Institute of Transportation Engineers' (ITE) Urban Street Symposium in 1999 reported on observations that led to the first four-to three-lane roadway conversions in Iowa. Prior to the mid-1980s, it was common practice to widen two-lane urban arterials to four-lane, undivided roads if traffic volumes exceeded 6,000 vehicles per day. According to Welch, "At public hearings, project engineers would state that corridor safety would improve if the two-lane roadway were widened to a four lane undivided roadway. Graphics would be shown to illustrate that additional acceptable gaps in the traffic stream would result, and motorists could avoid rear-end collisions by changing lanes and going around slowing/stopping vehicles. Those in opposition to the widening would argue that travel speeds would increase, pedestrians would have to cross a wider street, and noise would increase. In most cases, however, the four-lane undivided cross-section was selected as the preferred alternative because the only other alternative was generally to do nothing (i.e.: the roadway remains a two-lane facility)."

Welch's Table 1 shows the actual trends he found following such a two-lane to four-lane conversion of a road with average traffic volumes of 10,000 – 14,000 vehicles per day (vpd). It highlights the slight increase in traffic volume, delay, and speed, with a more substantial increase in accident and injury rates, and total value loss.

Table 1

Corridor Element	Change
• Traffic Volume	Increased 4 percent
• Corridor Travel Delay	Increased 4 percent
• Mid-block 85th% Speed	Increased 2.5 mph
• Traffic Traveling More than 5 mph Over Speed Limit	Increased from 0.5 percent to 4.2 percent
• Accident Rate	Increased 14 percent
• Injury Rate	Increased 88 percent
• Total Value Loss	Increased 280 percent

Table 1 –Table from Welch's 1999 Report following a two-lane to four-lane conversion

In contrast, positive safety and operations effects were experienced by localities that converted some wide, two-lane roads to three-lanes (one narrower lane in each direction with a TWLTL), suggesting the possibility of four to three-lane conversions as a potential way to improve safety and provide acceptable mobility. Welch (1999) reported data from nine conversions in Seattle, Washington and found that volumes were maintained while crash numbers went down.

Burden and Lagerwey (1999) provided traffic volume data for 18 road diets from four states and Canada, including the nine Seattle locations described by Welch. "Before" traffic volumes from the 18 road diets described in Burden and Lagerwey were between 9,700 and 23,000. In each case except one, traffic volumes were maintained or increased after the conversion. Lake Washington Blvd., in Kirkland, WA, with an initial volume of 23,000 vehicles per day, increased to nearly 26,000 after the conversion, and during one period was carrying about 30,000 vehicles per day. The one exception where the after volume decreased somewhat carried an initial 20,000 vehicles per day, which dropped to 18,000 in the after period suggesting the potential for traffic diversion to other routes. Huang, Stewart, and Zegeer (2002) also mentioned two road diet examples where traffic volumes decreased on the treated streets and increased somewhat on nearby routes: A conversion of Polk St from three lanes to two lanes in San Francisco was followed by an ADT decrease of 2% and ADT increases on two nearby parallel streets by 8% and 15% (actual volumes not reported). However, Polk Street also saw an increase in bicycle traffic from 37 to 52 during the peak hour. The conversion of Valencia Street in San Francisco also resulted in a 10% decrease in ADT, to 19,979, while the ADTs on four parallel streets increased by 2% to 8%. The number of bicycles, however, more than doubled on Valencia during the peak hour, from 88 to 215.

The City of Orlando, Transportation Planning Bureau carried out a variety of studies prior to a road diet conversion of Edgewater Drive. Following the conversion, traffic volumes dropped initially from 20,500 vehicles per day to 18,000, but then recovered to 21,000. Pedestrian volumes increased by 23 percent, and bicycle volumes increased by 30 percent. Parking use on Edgewater Drive also increased, and motorized traffic did not increase on nearby roads. All of these outcomes helped to meet eight of nine community objectives for the road diet conversion (*Edgewater Drive – Before and After Re-striping Results*, 2002).

In the case study examples described above, it is unclear how long after the implementation that traffic volume or other data were collected, or whether volumes had stabilized in the after period.

Knapp and Giese (2001) also carried out detailed simulation sensitivity analyses to attempt to confirm the reported operational impacts of four to three-lane road diet conversions. The results of the simulation analyses primarily confirmed the case studies assessments. Knapp and Giese (2001) noted that there may be some impacts to motor vehicles during peak periods of greater than about 1750 vehicles per hour. Simulation results indicated that a decrease in average arterial speed (ranging from 0 to 4 mph) for through vehicles would be expected for a three-lane configuration compared with a four-lane design, given a large range of peak-hour volumes, access densities, and access-point left-turn volumes (Knapp and Giese, 2001). The simulated arterial level of service for a converted roadway began to show a decrease when the bi-directional peak-hour volume was about 1,750 vehicles per hour (or 17,500 vehicles per day if 10 percent of the daily volume is assumed to occur in the peak hour) (Knapp and Giese, 2001). The models found that at higher access point densities (around 40 - 50 points per mile), four-lane undivided roadways with high left turning volumes begin to operate more like de-facto three-lane roadways in terms of speeds, as drivers avoid the left lanes on such four-lane roads.

Considering past research by others, Knapp recommended that a four-lane undivided to three-lane conversion be considered as a feasible option (with respect to volume only) when bi-directional peak-hour volumes are less than 1,500 vehicles per hour, but that some caution be exercised when the roadway has a bi-directional peak-hour volume between 1,500 and 1,750 vehicles per hour. However, Knapp pointed out that the results are for one idealized simulation case study, which included optimization of signal timing to minimize vehicle delay along the corridor.

Knapp and Giese (2001) also reported on 13 road diets in California, Montana, Minnesota and Iowa. A number of sites had volumes of around 20,000 to 24,000 ADT. Observed crashes decreased at all of the sites reported on by Knapp and Giese (for which data were available, see p. 28). Note that the observed crash reductions could have been affected by random effects due to regression toward the mean, although such effects would not be expected at all sites. Over all, travel speeds decreased at three of 10 sites with speed data available. Average speed increased at one location. The largest effects were on high end speeders (more than 5 mph over the limit, or above the 85^{th} percentile). Maximum

85th percentile or average speed reductions noted were three to four miles per hour. However, well-controlled estimates of crash reductions and operational data for different volume roadways were not provided.

Burden and Lagerwey (1999) indicated that road diet conversions prior to 1999 maintained capacity by keeping the same number of lanes (often as intermittent turn lanes/pockets) at intersections, where capacity and delay are usually most affected. However, if bicycle lanes or parking are added, as occurs more frequently in more recent conversions, it may not always be possible to maintain the same number of motorized vehicle lanes at intersections as in the before condition.

Knapp and Giese (2001) also identified detailed factors to consider in assessing the feasibility (and desirability) of road diet conversions. These factors included the desired as well as current purposes (function and environment) of the roadway, and a number of operational, design, network, and safety factors including:

- turning patterns and access density,
- signal timing and phasing,
- presence of turn lanes,
- presence of frequently stopping or slow-moving vehicles,
- the acceptable levels of service or delay for the corridor and intersections,
- the current situation and acceptable operations for side streets and driveways,
- pedestrian and bicycle activity and safety,
- availability of parallel routes,
- prevalence of crash types that may be most amenable to improvement with a road diet,
- The ability to enforce the left-turn-only function of the center lane (if created).

Earlier research and reviews (Zegeer, Stewart, Huang, and Lagerwey, 2002; Welch, 1999; Knapp and Giese, 2001) suggest that optimal safety benefits from road diets may be attained when:

- the roadway has a moderately high density of driveways and other uncontrolled access,
- crash severities are high,
- speeding contributes to safety problems,
- pedestrians and others crossing/accessing the main corridor are affected by the higher exposure of crossing multiple lanes, and
- frequent crash types that may be most amenable to improvement.

Clearly, each candidate site should be reviewed on a case by case basis (Knapp, Giese, and Lee, 2003a).

From analysis of crash patterns and operations, the crash types expected to benefit most include pedestrian crashes (by reducing the multiple threat risk), rear-end crashes involving left-turning vehicles, left-turning crashes involving far lane opposite direction vehicles, and sideswipe types of crashes involving same direction vehicles changing lanes to go around slowing, turning vehicles (Welch, 1999; Burden and Lagerwey, 1999). However, all types of crashes as well as crash severity may be reasonably expected to decline if speed reductions are obtained (AASHTO, 2010).

A conversion from four lanes may be unacceptable to a community, per Knapp, Giese, and Lee (2003b) if peak hour volumes exceed about 20,000 vehicles per day (or about 1000 vpd by direction). Yet the acceptability may depend on the change in level of service more than the magnitude. Additionally, Knapp et al. indicate that careful assessment is warranted if additional turn lanes are required at intersections along the corridor. The studies by Knapp and Giese (2001), Knapp, Giese, and Lee (2003a and 2003b) and Rosales (2007) provide more information on road diet case studies, goals and implementation considerations. Rosales relied heavily on Knapp and Giese and from case studies from around the globe to develop guidelines for identifying and developing potential road diet sites.

The remainder of this paper focuses on the safety effects of road diets. A secondary goal was to assess, if possible, the safety effects with regard to different volume roadways.

Study Methods

A search of road diet safety evaluation studies was performed. The search focused on identifying peer-reviewed safety evaluation articles and reports, particularly focusing on the period of 2002 through early 2013. The TRID (TRB Transportation Research Information Services Database joined with the OECD's Joint Transport Research Centre's International Transport Research Documentation Database) was searched, along with Web of Science, PubMed, and PsychInfo electronic databases for literature published since 2001. In addition, the Crash Modification Factors (CMF) Clearinghouse (http://www.cmfclearinghouse.org/) was searched. Correspondents also provided some papers. Search terms included "road diet" and "lane reduction." For earlier literature, we relied on several past reports and literature reviews that were conducted for preparation of the Highway Safety Manual (AASHTO, 2010). Targeted internet searching was performed, as well as review of secondary sources.

Results and Discussion

Six road diet safety evaluation studies were identified. Three of the studies have been published in peer-reviewed publications (Chen et al., 2013; Huang, Stewart, and Zegeer, 2002; and Pawlovich, Wen, Carriquiry, and Welch, 2006). A fourth was part of a large National Cooperative Highway Research Program (NCHRP) study that developed CMFs for the Highway Safety Manual (Harkey et al., 2008). For the NCHRP study, data previously used by Pawlovich et al. (15 Iowa sites), and by Huang et al. (30 sites from California and Washington) were reanalyzed using an empirical Bayes (EB) approach and larger groups of reference sites (Figure 1). An additional paper by Persaud et al. (2010) reported further estimates derived from using both full Bayes and empirical Bayes methods, again using the Iowa data. Thus, three of the key studies have used overlapping data from a total of 45 treated sites plus comparison sites. A few additional studies were identified. Most were reanalyses of data covered by the other papers.

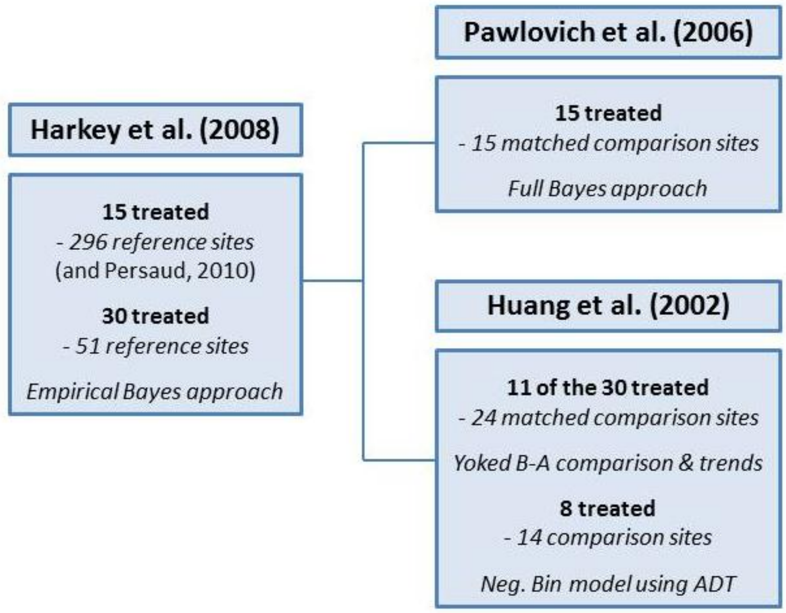

Figure 1. Data and relationships of three of four reviewed studies.

The most robust evaluations use methods to control for regression to the mean (RTM, the tendency for crashes to fluctuate around a mean, and thus change year-to-year whether or not a treatment is implemented), changes in traffic flow, and general crash trends using a comparison group and statistical procedures. By using large groups of reference sites that are similar to the treated sites to generate estimates of expected crashes for similar types of roads (in the absence of treatment), the EB methodology can help reduce the influence of random fluctuations in crashes and therefore control for regression toward the mean (RTM) effect. In addition, effects of changes in traffic volume over time, or due to the treatment are controlled with this method.

CMFs provide estimates of the safety effects of treatments as a multiplier of prior crashes. To obtain an estimate of the expected percent change (reduction) in crashes, use the calculation of (1 – CMF)*100. Study characteristics and estimates of crash effects (percent increase or decrease) with standard errors or confidence intervals are reported in Table 2 for the four studies listed.

Based on the CMFs produced, Harkey et al reported (in Appendix C) estimates of total crash reductions of 47 percent for the Iowa sites (Table 2). For this set of sites, Pawlovich et al. had used full Bayesian methods and derived expected total crash reductions of 25 percent normalized to a per mile basis. Due to the different outcome measures, the estimates are not strictly comparable, but both indicate substantial, significant crash reductions with small standard errors of the estimates. In addition, Persaud et al. also analyzed the Iowa data using a full Bayes approach, and with both the smaller and larger sets of comparison sites, and obtained very similar estimates of 47 to 49 percent total crash reductions per site per year.

The 47 percent expected crash reduction would be most accurate when considering road diets for routes (mostly State or U.S. highways) passing through small urban areas of around 17,000 average population, and with traffic volumes in the range of about 5,000 to 12,000 per day. The average before and after traffic volumes reported also suggest that traffic volumes were maintained or increased slightly between the before and after periods, although the data for individual sites were not available. Thus, there was no evidence of volume shifts implying potential traffic diversion to other roads. There were, however, no estimates of disaggregate effects for different volumes or other conditions of the roadway, nor of particular crash types (rear-end, pedestrian, left-turn, etc.).

Estimates of 19 percent total crash reductions were obtained for the sites from California and Washington (Harkey et al.., 2008). The 19 percent estimates based on California and Washington data would be most applicable to corridors in larger suburban/urban areas (populations up to 269,000) with average daily traffic volumes ranging from 5,500 to 24,000 vehicles (HSIS, 2010). Again, estimates by disaggregate crash types, traffic volumes, or other conditions were not reported.

The Harkey et al. 19 percent estimated reduction is considered a more reliable estimate to replace the earlier estimate by Huang et al. of a non-significant change in crashes (Table 2). In using empirical Bayes procedures, Harkey et al., were able to use all 30 of the initial study sites considered by Huang, and a large group of reference sites to develop estimates of safety effects.

The reason for the larger crash reductions in Iowa compared to the California and Washington sites was speculated to be due to potentially larger speed reductions at the Iowa sites (Harkey et al., 2008). There were up to 5 mph reductions in 85th percentile speeds and large reductions in percentages of vehicles exceeding by 5 or more mph at one of the Iowa sites. Researchers speculated that speed reductions for vehicles approaching and going through small urban centers in Iowa on mainly U.S. and state highways might be greater than those expected in the larger urban areas of California and Washington, where speeds may have been lower before treatment (HSIS, 2010).

A combined estimate of 29 percent (1.6 percent standard error) in total crash reductions resulted for all the Iowa, Washington State and California sites combined (not shown in the table). This estimate could be used as a more general estimate of expected effect of road diets or for localities with location types intermediate to the Iowa compared with California and Washington sites.

Most recently, a study of 460 road diet sites in New York City estimated total, multi-vehicle, pedestrian, and injury and fatal crash effects for 460 segments, and for 324 intersections adjacent to the road diet sections (Chen et al., 2013). The intersections' zones of influence included crashes within 100 feet of the intersection. Total crash reductions of 67 percent were estimated for treated segments with an estimate of 13 percent reduction in total crashes at the nearby intersections. In addition, significant reductions in multi-vehicle and fatal and injurious crashes were reported for both segments and intersections along with a lower trend in pedestrian crashes for segments only (Table 22). Study design and analysis methods were used to control for potential regression to the mean effect. However, traffic volume data were unavailable for use in analyses, so a potential influence of changes in traffic volume on crashes cannot be ruled out.

The paper by Gates, et al. 2007 was not published, and due to an incomplete description of the data and study, the crash data results are not further described. However, speed data reported by Gates et al., indicated that mean speeds were reduced at 18 out of 20 sites, and 85th percentile speeds were reduced at 15 out of 20 sites. Reductions of around 2 mph in mean speeds were statistically significant at 3 of the 18 sites with reducing trends.

Table 2. Study Characteristics and Results of Safety Evaluations of Road Diet (mostly four to three-lane including center, two-way left turn lane) conversions.

Reference	Study Methods	Treatment Sites	Comparison Group	Control for ADT	Control for RTM	Other	Study Periods	Outcome Measures	Observed Crashes - Treatment	Observed Crashes - Comparison	Estimated Change in Crashes due to treatment
Chen et al., In Press	Before-After with comparison group; ANCOVA model to estimate coefficients, combining treated and untreated sites to estimate expected crashes without treatment	460 segments, NYC	3364 matched segments with geographic proximity, but not adjacent (to avoid spillover effects)	No	Possibly. The method has been used in the medical research field but not yet validated in road safety	No information available on whether traffic volumes changed before to after	[±]B: 5 years A: 2 years all sites	Total (reportable) crashes	B: 0.12 avg. crashes per location year; A: 0.05 avg. crashes per location-year	B: 0.10 average crashes per location year A: 0.12 avg. crashes per location-year	*(-67% +/- 7%)
								Injurious and fatal crashes	n.a.	n.a.	*(-70% +/- 9%)
								Multi-vehicle crashes	n.a.	n.a.	*(-67% +/- 7%)
								Ped crashes	n.a.	n.a.	(-41% +/- 27%)
	Before-After with comparison group; same ANCOVA methodology as for segments	324 intersections adjacent to road diet sites, NYC	2342 matched intersections	No	Possibly. See above	No information available on whether traffic volumes changed before to after	B: 5 years A: 2 years	Total (reportable) crashes	B: 0.84 avg. per location-year A: 0.82 avg. per location-year	B: 0.98 avg. per location-year A: 0.82 avg. per location-year	*(-13% +/-5%)
								Injurious and fatal crashes	n.a.	n.a.	*(-17% +/- 6%)
								Multi-vehicle crashes	n.a.	n.a.	*(-19% +/- 10%)
								Ped crashes	n.a.	n.a.	5% +/- 16%
								Bicycle crashes	n.a.	n.a.	21% +/- 30%
Harkey et al., 2008; also Persaud et al., 2010	Empirical Bayes Before-After with reference group to develop safety performance functions and expected crashes with and without treatment	15 IA sites	296 reference sites	Yes	Yes		Trt. Group B: mean 17.5 years (range 11 to 21 years); Trt. Group A: mean 4.5 years (range 1 to 11 years); Ref. group: mean 21.8 years (range 5 to 23 years)	Total crashes	B: 23.7 per mile-year; A: 12.2 per mile-year	26.8 per mile-year	*(-46.6%) (2%) (-47%) (1%) using full Bayes (from Persaud et al.)

Reference	Study Methods	Treatment Sites	Comparison Group	Control for ADT	Control for RTM	Other	Study Periods	Outcome Measures	Observed Crashes - Treatment	Observed Crashes - Comparison	Estimated Change in Crashes due to treatment
	Empirical Bayes Before-After with reference group to develop safety performance functions and expected crashes with and without treatment	30 CA & WA sites	51 reference sites	Yes	Yes		Trt. Group B: mean 4.7 years (range 1.8 to 8.5 years); Trt. Group A: mean 3.5 years (range 0.6 to 8.8 years); Ref. Group: mean 7.8 years (range 4.5 to 12.2)	Total crashes	B: 28.6 crashes per mile-year; A: 24.1 crashes per mile-year	42.2 crashes per mile-year	*(-18.9%) (2.5%)
Huang et al., 2002	Before-After with Matched (yoked) Comparison	11 (of 30 original sites, CA & WA)	25 matched comparison sites	Yes	Possibly. But pre-EB, not as effective as EB method.	Excluded crashes at intersections or other transition areas. Excluded crashes for 3-month transition period around intervention completion.	B: at least 1 year for most sites A: at least 1 year for most sites.	After-period proportion of total Before and After crashes	B: 1327 total crashes, all sites A: 741 total crashes, all sites	B: 5045 total crashes, all sites A: 3510 total crashes, all sites	*(-6%) (0.3% to 10.6%, 95% Conf. limits) Lower proportion of after period crashes for road diet sites relative to comparison sites
	Before-After with Comparison group	8 (of 30 original sites, CA & WA)	14 matched comparison sites	Yes	Yes	Crashes per mile of roadway treated as a log-linear function of ADT, and other explanatory variables.	B: at least 1 year for most sites A: at least 1 year for most sites.	Total crashes per mile	Not reported for this subset	Not reported for this subset	No significant effect of treatment
Pawlovich et al., 2006	Full Bayes Before - After comparison with same before-after change point used for untreated, matched comparison group	15 IA	14 matched sites (1 dropped due to unreliable data)	Yes	Yes	ADT treated as a linear predictor, but volumes did not change significantly between Before and After periods	B: mean 17.5 years (range 11 to 21 years); A: mean 4.5 years (range 1 to 11 years)	Total crashes per mile	not reported, but same data, in part, as in Harkey et al.	n.a.	*(-25.2%) (23.2 to 27.8%, 95% C.I.)
								Total crash rate per mile	not reported, but same data in part, as in Harkey et al.	n.a.	*(-18.8%) (17.9% to 20%, 95% C.I.)

±B = Before period; A = After period in any column in the table.
*Statistically significant effects

Michigan study

The sixth study identified is a report for a State agency that also has not yet been published in a peer-reviewed format. Lyles et al. (2012) reported on the crash effects of 24 road diets around Michigan. Several crash effect estimates using different methodologies were provided in the study. An average CMF developed using a naïve before-after comparison was estimated at 0.63 (a 37% crash reduction). A CMF of 0.91 (9 percent total crash reduction) was derived from a simple unweighted average for all 24 sites combined (regardless of corridor length or number of crashes per site). The latter CMF was adjusted based on city-wide crash trends rather than by using a similar comparison group of untreated roadways. Potential regression toward the mean may not be fully controlled by either of the two previous approaches, and it is not clear how volume trends were accounted for. It appears that for the estimate adjusted by the city-wide crash trends, the comparison group was included the treated corridors. If so, the trend adjustment factor would incorporate crash effects due to the treatment, potentially causing an understatement of effect, especially if the treated corridors accounted for a large percentage of crashes. When conducting controlled, before-after evaluations, it is essential that a comparison group with similar characteristics to those treated, but that are not affected by the treatment, be used to estimate the crash effects likely attributable to the treatment (Hauer, 1997).

State-of-the art E-B methods were used to derive disaggregate estimates for four of the 24 sites for which suitable comparison sites could be identified. Three years of before and after crash data, apart from the construction year, were used for each site. However, it is not clear how AADT data were used in the evaluation. These individual corridor comparisons resulted in CMFs of .98, 0.97, 0.93, and 0.83 (expected crash reductions of 2 percent, 3 percent, 7 percent and 17 percent, respectively). However, the estimated crash reductions were not statistically significantly different from zero for any of the four corridors. It is not clear why data for all of the four sites were not combined, for, perhaps, a more robust analysis. In addition, if a larger reference group is used, the importance of matching of exact characteristics takes on less importance. A larger reference group is also more effective in accounting for RTM (Harwood, et al., 2002)

The authors focused their main conclusions on the CMF estimates derived from an unweighted average of before-after comparisons using all 24 sites (without accounting for similarity of corridors to those treated, nor length, or numbers of crashes by corridor) and adjusted for city-wide trends. In addition, certain crash types thought not to be affected by the treatment were excluded. However, since road diets may reduce operating speeds, all crash types might reasonably be reduced, particularly more severe crashes. As mentioned, there are some issues with control for traffic volumes, description and suitability of comparison groups used, and other study details that limit confidence in the findings. As acknowledged by the authors, the estimates derived are clearly affected by the comparison group used, with very different estimates of effect being reported, depending on which reference group was used.

Data provided also showed that there were 33 fatal and A-type (disabling injury) crashes in the three year before period for all 24 sites combined, and 9 fatal and A-type crashes in the three-year after period for all sites combined. Although there is mention of an overarching decreasing trend in crashes of all severities in Michigan for a 15 year period spanning the study period, specific data for the comparison city(ies) during the study period were not provided.

Although the primary intent of this review was not to review operational impacts, these impacts are of course a concern to network providers and transportation consumers. Lyles et al. also modeled intersection approach delay for one or both road diet approaches at nine different intersections within road diet corridors. They used baseline peak-hour traffic volumes and turning percentages to establish the baseline worst case delay. Volume increments used were 750, 1,000, 1,250, 1,500, 1,750, and 2,000 vehicles per hour (vph), holding turning percentages constant. The authors concluded that delay was affected with volumes as low as 10,000 vehicles per day (vpd), or more particularly 1,000 vehicles per hour (vph). The earlier studies by Knapp et al. suggested less sensitivity to volumes up to levels of 1,750 vph, and that caution begin to be exercised with volume thresholds of around 1,500 – 1,750 vph. As reported by Lyles et al., most of the models showed virtually no difference in delay between 3-lane and 4-lane at 1,000 vph, with 3-lane delay beginning to rise at a higher rate at around 1,000 – 1,250 vehicles per hour compared to a more gradual rise for 4-lane sites. (Interpretation was somewhat complicated by using display graphics with different scales for different graphs). Over the 17 model results shown, the average "failure" point (defined as an LOS D or lower with 55 seconds intersection delay) was not reached until 1,500 vph, which is more in line with the earlier Knapp study. This study also reported that "An analysis of existing conditions was done for each site and results were checked for any major issues such as high delay or queue length values (there was none)." As mentioned in the introduction of this review, some jurisdictions, when feasible, maintain capacity at intersections by using intermittent turn lanes and signal timing adjustments. In their models, Lyles et al. generally held signal phasing as a constant.

Others have modeled the potential impacts of different forms of intersection traffic control in conjunction with a conversion, with one paper finding that a modern, single-lane roundabout, in conjunction with a three-lane configuration, would be a viable and safer alternative to four-lane undivided, or three-lane with two-way stop control with up to 50 percent higher traffic volume (Russell and Mandavilli, 2003). Rosales (2007) describes other examples, including analysis of Grand Blvd., Vancouver, WA. A 20-year forecast was conducted that found that the addition of right-turn lanes at three intersections along the converted corridor would yield an intersection LOS of D or higher, the same as the four-lane configuration. In addition, the potential for traffic diversion was analyzed, with a finding that an adjacent parallel roadway might expect a 5 percent increase from diverted traffic. This percentage was considered acceptable.

Conclusions

A relatively small number of robust studies have analyzed the safety impacts of road diet conversions, mostly from four-lane, undivided corridors to three-lane corridors including TWLTL (frequently with added bike lanes). The most robust studies have, however, encompassed a substantial number of converted sites and comparison locations. Based on these studies, road diet treatments seem to be one of the success stories with regard to crash and speed reductions.

Road diets are also compatible with providing a number of other community and roadway use benefits. In addition, conversions utilizing existing right of way can be very economically implemented through the use of paint, but perhaps enhanced with additional measures such as raised medians and turn pockets.

The most robust estimates range from 19 percent average reduction in total crashes on corridors in larger urban areas to 47 percent for more rural highways passing through small urban areas. Crash reductions have been documented for a range of conditions including highways passing through smaller localities, for corridors in larger urban/suburban areas, as well as intensively urban New York City.

Actual crash reductions can be expected to vary depending on the site conditions, crash types analyzed, and methodologies used. In terms of site conditions, there has been significant conjecture that pre-conversion conditions such as density of unsignalized junctions, frequency of left turning movements, numbers of slowing or stopping vehicles, changes in operating speeds, and prevalence of certain crash types, among other factors may affect results obtained, but there are insufficient data at present to support or refute these conjectures. The extent of speed reductions achieved may also help to explain variation in the degree of safety effects that has been noted in different environments. Lower operating speeds have the potential to affect all types of crashes and crash severity

Impacts on more severe crashes (fatalities and injuries) and operating speed changes should be a prime consideration in future evaluations. Since it is typically more challenging to detect effects on lower numbers of severe crashes, documenting effects on travel speed distributions would help to document safety benefits and reduction in risk of more severe injuries. Motor vehicle speed is a prime safety consideration for pedestrians.

However, there are still questions about what conditions are most conductive to the greatest safety benefits, as well as maintenance of good operational and access conditions for various users. Road diet treatment generally seems compatible with maintaining motor vehicle capacity under the volume conditions studied, most often in moderate ranges from around 5,000 up to 24,000 vehicles per day, or up to around 1,500 – 1,750 vehicles per peak hour. Case study evidence suggests that other types of traffic, including bicycles and pedestrians, may increase after a road conversion.

It is not entirely clear whether the mobility assessments to date have well-captured actual operational effects of road diets, or whether short term traffic diversion noted in some instances have continued over time. Some studies have shown a short term shift in flows to other corridors, with volumes returning in time. Much of the information to date is in anecdotal or case study format, or based on simulation modeling exercises, which necessarily simplify and omit parameters that may have a bearing on flows. Many of the "worst case" volume scenarios in simulation studies might never occur, or might be mitigated through optimizing signal timing, provision of intermittent turn pockets or roundabouts at intersections, shifts in travel mode if alternate facilities are provided, and other outcomes that have been reported by practitioners.

Road diet conversions to three-lanes seem to be a low-cost way to enhance safety for a fairly wide range of urban and suburban four-lane, undivided corridors of low to moderate volumes. If a road diet additionally meets other local objectives, then it should be considered a viable option based on the safety evidence.

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Pedestrian and Bicycle Information Center

730 Martin Luther King Jr. Blvd., Suite 300
Chapel Hill, North Carolina 27599-3430
pbic@pedbikeinfo.org
888-823-3977