LITERATURE REVIEW

Operational Effects of Road Diets

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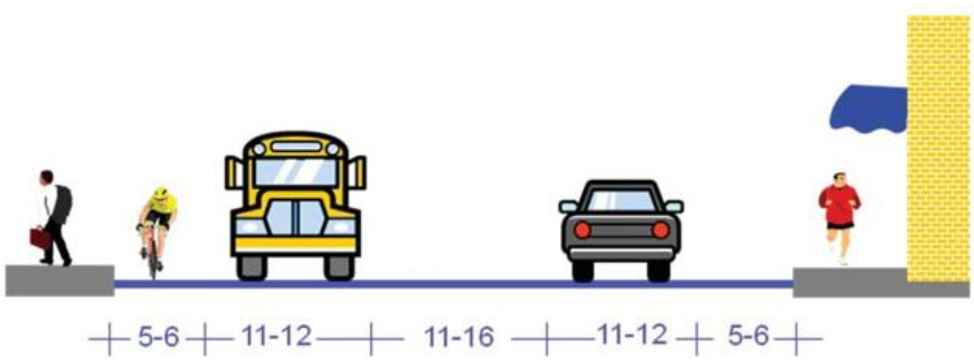
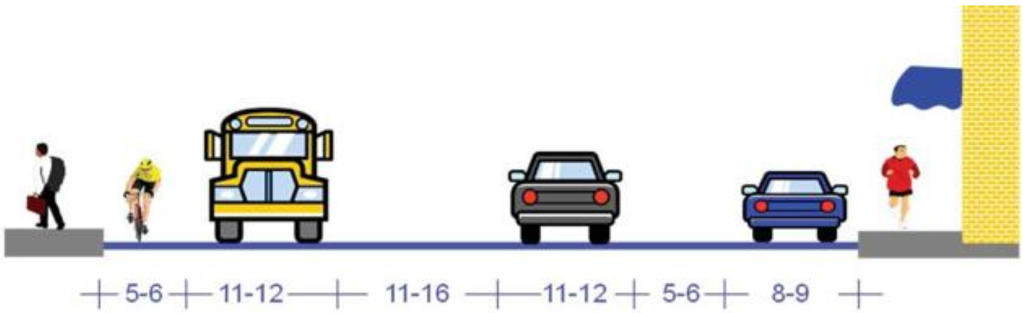
Following WWII, the demand for personal automobiles rose dramatically, and transportation networks were engineered to accommodate the growth of private ownership, focusing right-of-way priorities to increase the capacity of motor vehicles (Winters, Mitra et al. 2016). In more recent years, the emphasis has shifted to exploring ways to serve more diverse road users such as bicycles and pedestrians, and doing so with increasingly limited budgets. The road diet has proven to be a cost-effective and practical way to meet the needs of various users in terms of both safety and operation. The road diet reallocates roadway space to better meet current needs, thus working within the existing footprint and eliminating the need for additional right-of-way, extensive engineering, lengthy environmental studies, and costly construction (FHWA 2016).

The concept of the road diet is relatively new; such conversions were not well researched in the US until the 1990s (Gates, Noyce et al. 2007). The movement towards Complete Streets design emphasized the need to accommodate multiple users, both motorized and non-motorized, and a road diet can be incorporated into such initiatives(Winters, Mitra et al. 2016, Ntonifor 2017, Ohlms, Dougald et al. 2020).

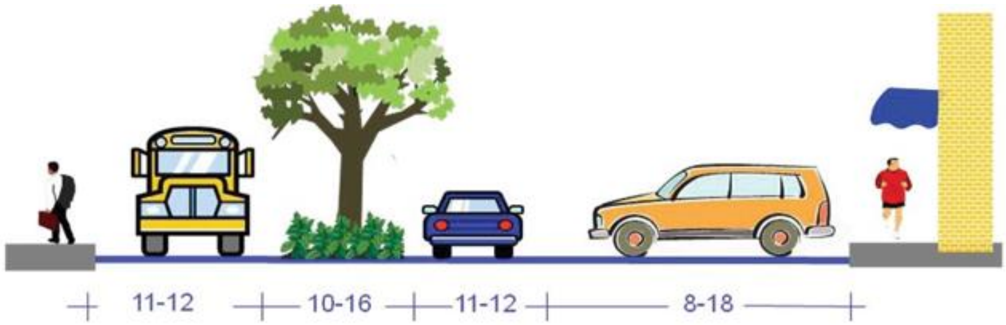
The most common configuration converts a 4-lane, 2-way roadway into a 3-lane corridor with 2 lanes of travel and a dedicated 2-way left turn (TWLT) lane. The additional space can then be used for bicycle lanes, sidewalks, additional street-side parking, and sometimes landscaping. Stamatiadis, Wang et al. (2011) offered three cross-section examples:



Example cross-section with two-way left turn lane and bicycle lanes



Example cross-section with two-way left turn lane, bicycle lanes and parking



Example cross-section with landscaped median and parking (back-in shown)

While a road diet is not always a viable option, the follow-up analyses that were reviewed indicated that most jurisdictions felt the change had met the project goals, and the public generally reacted favorably. Four-lane undivided highways have historically high crash rates, in part because drivers tend to use the inside lanes for higher speeds (Federal Highway 2015). On the other hand, the inside lane sometimes acts as a de-facto left turn lane, with drivers waiting for a gap in traffic to make the turn, causing queueing behind the motorist. However, Knapp, Chandler, et al, (2014) pointed out that when this arrangement works successfully, with the majority of through traffic using the outside lanes, allowing for left-turning drivers to use the inside lanes as left-turn lanes, a road diet may not be appropriate. Other considerations that might make a road diet less than ideal include potential blockages by stopped service vehicles creating additional delays and congestion, increased delays at driveways, and lack of passing opportunities (Ntonifor 2017).

Traffic volume is an important determining factor; while earlier studies determined that an ADT of 10,000 - 17,000 was the upper limit for road diet, later work has determined that roads with significantly larger volumes, up to 23,000 vehicles per day (vpd), could be considered (Stamatiadis, Kirk et al. 2011). The volume of side roads also needs to be evaluated, since simulations have shown that road diets on roads with relatively low ADT could fail depending on the side street volumes at the intersections (Stamatiadis, Kirk et al. 2011). Gates, Noyce et al (2007) recommended road diets for corridors averaging ADT values prior to the conversion of 8,300 to 17,400, with speed limits 30-40 mph, and unsignalized access densities of 16 to 51 access points per mile. According to Aljamal, Voight, et al. (2021), a dedicated left-turn lane is indicated if the left-turn volume is greater than 20 percent of the total approach volume, or if the volume of vehicles making left turns exceeds 100 per hour in peak traffic periods. Those same authors maintained that road diets can be considered in roads with an ADT as high as 24,000 as long as there are large left-turn volumes, but that operational risk begins at 20,000 ADT, and there is dispute in the estimation of acceptable ADT volumes at peak time. Michigan studies found that delays increased significantly when volume during peak hours exceeds 1,000 vpr (Chacon-Hurtado, Yang et al.

2018). On the other hand, Knapp and his team maintained that peak-hour ADTs of 7500 – 8000 were acceptable for road diet applications.

Posted speed limits also need to be taken into consideration for road diet projects. Rocchi (2011) asserted that only roadways with posted speeds less than 60 kph (37 mph) should be reviewed for potential projects. Gates, Noyce et al. did not recommend road diets for corridors with speeds over 40 mph.

Road diets are not necessarily designed to improve traffic operations, and if a roadway segment is overwhelmed with traffic volume, related operations loss in terms of congestion, delay and unreliability could offset any safety benefits of such a project (Chacon-Hurtado, Yang, et al. 2018). That said, road diets do tend to have a traffic calming effect. Speeds are generally slower and lane interactions are reduced following a project. One Staten Island project found that the number of drivers speeding after the road diet was put in place decreased by 34 percent in the southbound lanes, and 21 percent in the northbound ones (FHWA 2015). Speeding had also been a problem along a Chicago corridor, but drivers closely adhered to the 30 mph speed limit following a road diet (FHWA 2015).

While traffic operation improvement may not be the first priority for road diet applications, many studies suggest that projectss generally do not reduce travel times at a statistically significant level, and may improve traffic flow {Gudz, Fang, Hardy 2016). In the nine Minnesota sites studied by Gates, Noyce, et al. (2007), the conversions showed little to no impact on traffic operations. With a reduction in speed differential, more consistent traffic flow could be maintained, eliminating much of the "accordion-style" bunching of more traditional designs. Because side-street traffic has fewer lanes to cross, side street delays are often reduced. {Knapp, Chandler 2014). An evaluation of road diet corridors for the Kentucky Transportation Cabinet found that side street traffic at unsignalized intersections saw smaller delays on the three-lane road than on the four-land roadway in all scenarios (Stamatiadis, Kirk, et al. 2011). The same authors noted that the queue length on the main road was smaller or the same on the road diet as opposed to the four-lane road at signalized intersections. Delays at unsignalized intersections were slightly higher with the three-lane option, but were very minor, generally less than 2.5 sec/veh. Other road diets had less favorable operational outcomes; one conversion in Grand Rapids, MI led to longer queue lengths (northbound increase from 81 feet before to 180 feet after in the PM) and increased travel times (average increase of 19 to 52 seconds through the corridor), leading to a subsequent increase in emissions (FHWA 2015).

Traffic volume often decreases following a road diet conversion, and critics of such projects sometime voice concern over increases on adjoining roadways. This does not always seem to be the outcome, however. Volumes along a road diet corridor in Pasadena, CA decreased by approximately3000 – 4500 vehicles per day; nonetheless vehicular levels of service remained unchanged and traffic counts on nearby roads remained stable (FHWA 2015). A Seattle project saw a 1 percent decrease in volume, with peak hour capacity maintained at pre-project level. Traffic volumes on parallel streets, however, are down by 12 to 34 percent (FHWA 2015). A one-year evaluation of a San Francisco road diet did not study traffic on adjacent parallel streets, but the lack of congestion and steady traffic flow on the main street led the author to assume there would be little reason for traffic to divert to those streets, and no complaints had been received of spill-over traffic on adjacent streets (Provence 2005).

These projects also appear to benefit older drivers. The traffic calming effects are helpful to those with slower response times and reflexes, and road diets can also provide sight distance improvements for mid-block left-turners – drivers in four-lane undivided roadways can experience negative offset with opposing traffic, limiting the view (Knapp, Chandler, et al. 2014).

Optimizing signals along the corridor is a necessary component of a successful road diet project. Evaluation of a road diet installed along a corridor in Washington, D.C. showed good performance at all but one of the signalized intersections. Traffic volumes at this intersection increased dramatically as a result of diverting traffic volumes on the side street from the unsignalized intersection. It was found that performing a lane configuration improvement and signal timing optimization mitigated the issue at the affected intersection (Alijamal, Voight et al. 2021). Knapp, Chandler et al. (2014) also recommended adjusting the positioning of the signal heads to better align with new land configurations, with a minimum of one signal head installed over each traffic lane. Rocchi, Craik (2011) suggested considering a left turn protected phase.

Since the purpose of road diets is to reallocate roadway space to better meet the needs of both motorized and non-motorized users, there are obvious benefits to bicyclists and pedestrians. LOS scores generally increase for both modes with the reduction of travel lanes, reduced speeds, and the introduction of bike lanes (Knapp, Chandler, et al. 2014). Pedestrian refuge islands are often included in road diet conversion, which, combined with fewer travel lanes to cross allows pedestrians to have a greater feeling of safety. Bicycle lanes are often buffered with a painted or raised barrier, and sometimes are separated from traffic by a parking lane (Knapp, Chandler, et al. 2014). Case studies confirm these findings; bicycle use increased by 243% following a road diet project in Davis, CA, although there was no statistical increase in pedestrian counts at the intersections along this corridor. The report noted that, whether the increase came from new bicyclists, or ones who transferred from other routes, it was clear that the conversion resulted in a more desirable facility for bicyclists (Gunz, Fang, Hardy 2016). Bicycle traffic tripled following a Los Angeles road diet (FHWA, 2015). Prior to a road diet project in San Francisco, residents complained about the practice of automobiles parking with two wheels on the sidewalks due to narrow parking lanes. This practice impeded pedestrian traffic. Sidewalk parking was eliminated following the conversion, and landscaping was added to the sidewalk area. As a result, the number of pedestrians increased by 49 percent in the PM hours, with a 37 percent increase in bicycle usage in the PM hours (Provence 2005).

In addition to safety and mobility benefits for bicycles and pedestrians, road diets have resulted in improvements to the general livability of the corridor. Knapp, Chandler, et al. (2014) use the definition of livability as being “about tying the quality and location of transportation facilities to broader opportunities such as access to good jobs, affordable housing, quality schools, and safer streets and roads.” Increase in quality of life and economic development has been noted by many studies on road diets. In one example, several residential facilities along the corridor that had been previously unrented for two years were rented following the road diet conversion. The owner credited improvements attracting bicycle enthusiasts to live and work in the area, contributing to the overall economic progress (FHWA 2015). Another study reported that stakeholders had come to view roadway changes as important factors to the economic success, safety and vitality of the city (Ntonifor 2017). Rosales, Knapp (2005) looked at road diet projects from several US states, Canada, and New Zealand. Results found that redevelopment and renovation work was progressing at an increased pace, with several new home and business improvement projects, and a growth in “front yard” activities on road dieted streets. A project along the University of Chicago drew praise from the community, noting an increase in community livability. In particular, the addition of bicycle lanes was beneficial for students, staff and visitors (FHWA 2015). Aljamal, Voight et al. (2021) noted that the D.C. road diet they evaluated was credited with making local businesses more accessible.

Transit and freight needs also need to be considered when planning road diet projects. Knapp, Chandler et al. (2014) addressed transit needs, noting that conversions should not cause unnecessary delays. As buses often use the right-most lane, eliminating travel lanes could result in bus stops blocking the single through lane. As a result of one Michigan project where the roadway had originally served as a transit route, the bus company decided to relocate the route due to increased travel times (FHWA 2015). However, other jurisdictions have found ways to accommodate transit into the overall plan. When local bus companies expressed a concern about removing the bus completely from the travel lane, Grand Rapids, MI used expanded bicycle lanes to provide a space for transit buses to leave the through lane, thus eliminating backups in traffic (FHWA 2015). Chicago city planners worked closely with the Chicago Transit Authority (CTA) on a road diet project along a primary bus route, with headways ranging from 5 to 20 minutes throughout the day. The resulting design included separated bicycle lanes in coordination with bus stops which maintained efficient bus services (FHWA 2015). Other projects also showed that transit could be successfully integrated into road diets. Rosales, Knapp (2005) included efficient transit activity as part of the livability impacts of the road diets they evaluated. In San Francisco, a one-year evaluation of a project showed that transit travel times improved by 6 percent, and the number of passengers getting on and off the buses within the corridor increased by 35 percent (Provence 2005). A Seattle project showed that transit travel times remained stable, and ridership increased by 30 percent between 2010 and 2013 (FHWA 2015).

Truck and freight traffic can also be impacted by road diet conversions, and sometimes negatively. An Iowa road diet narrowed travel lanes along a truck route from 13 feet to 10 feet, which seemed too narrow for truck drivers' comfort. In a similar effort to narrow lanes in order to promote traffic calming and reduced speeds, projects in Chicago and Michigan installed shoulders and buffers between bicycle and travel lanes, keeping lane widths to a maximum of 12 feet (Knapp, Chandler et al. 2014). Freight operators have special needs, especially those delivering goods to business along a road diet corridor. To better accommodate these users, Knapp, Chandler et al. (2014) shared recommendations from the New York State Association of Metropolitan Planning Organizations (NYSAMPO) for accommodating freight traffic in road diets. The considerations included:

- Current land use (what volumes and types of trucks use the area to sustain current businesses, etc.?)
- Truck size (does the corridor connect to larger industrial properties, or generally serve smaller, local businesses?)
- Delivery parking areas (can alleys or side streets accommodate truck parking?)
- Intersection design (can turn radii accommodate larger trucks if needed?)

Road diet projects can be funded through a number of sources, and project costs can be dramatically reduced by coordinating a road diet along with regularly scheduled pavement overlays or restriping work (FHWA, 2016). Funding is available through federal programs, such as the Surface Transportation Program (STP) and Highway Safety Improvement Program (HSIP). Some states have been innovative in locating funding sources for road diet installations; Washington State DOT has made use of pedestrian and bicycle programs, as well as transit grants, and Seattle DOT has used Safe Routes to School funds grants (FHWA). A San Francisco road diet was approved for Transportation Fund for Clean Air (TFCA) funding (Provence 2005).

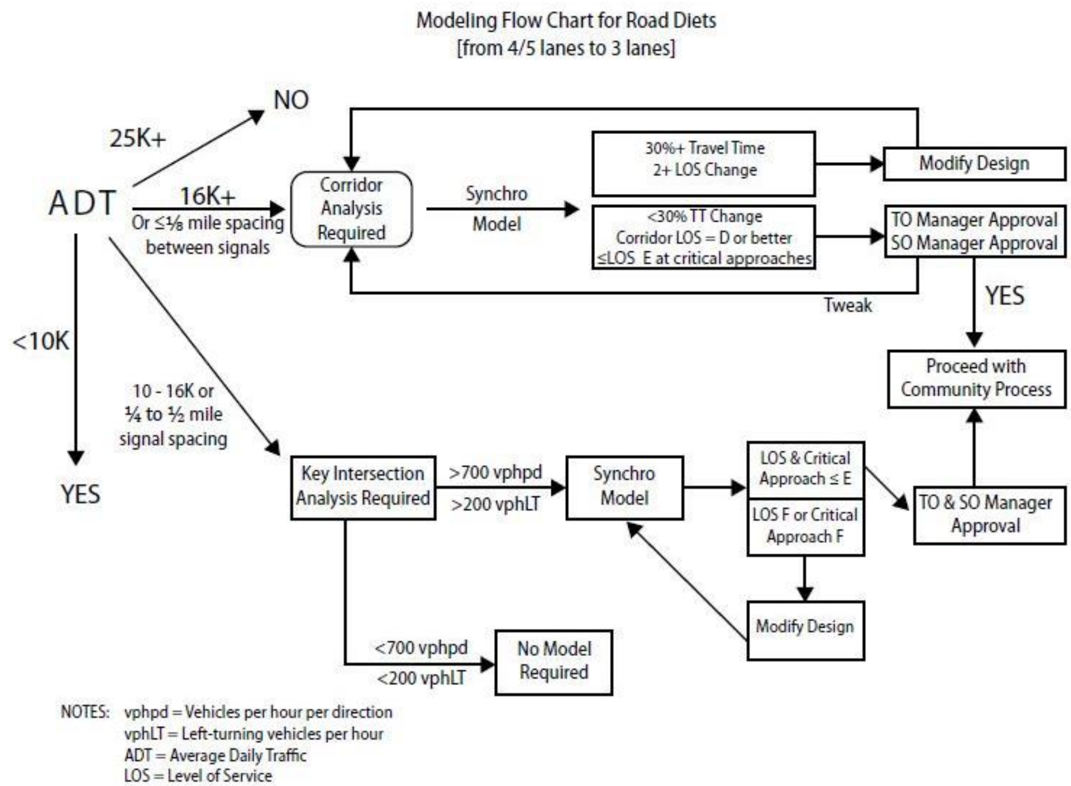
Maintenance costs can also be reduced through a road diet, since facilities such as bicycle lanes, medians, TWLTs and wider shoulders receive less wear than travel lanes, therefore requiring less regular maintenance. Having fewer lanes to plow during snow storms can also result in cost savings (FHWA 2016). However, maintenance budgets in some states and jurisdictions are based on motor vehicle lane-miles. A road diet can reduce these lane miles by one-quarter, reducing the maintenance funding accordingly (Knapp, Chandler et al. 2014).

As road diets become an increasingly popular and practical way to meet the safety and operational needs of all users with reduced costs, there have been numerous efforts to define the criteria to be considered for successful road diet projects. Knapp, Chandler, et al. (2014) notes that Seattle DOT considers the following when selecting a road diet corridor:

- Volume of traffic (up to 25,000 vehicles per day)

- Number of collisions for all modes (motor vehicle, pedestrian, bicycle)
- Vehicle speed
- Number of lanes
- Freight usage
- Bus stops and routing
- Travel time
- Accessibility

Based on these facets, Seattle DOT developed the following flow-chart:

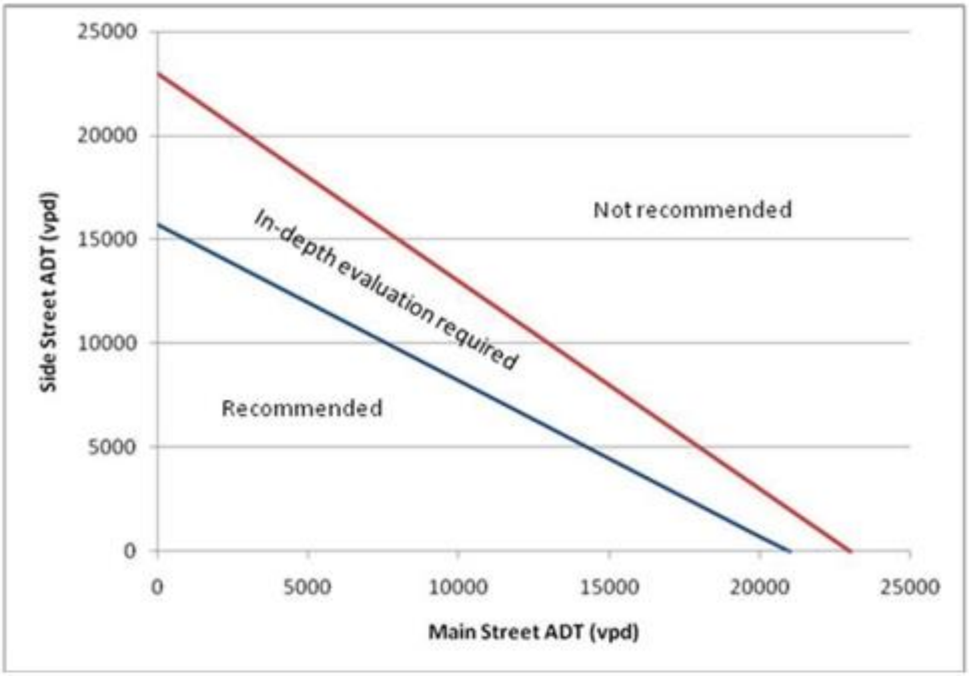


Knapp, Chandler, et al. (2014)

Seattle DOT further conducts before-and-after studies to determine the effects of each converted corridor comparing the following conditions:

- Volume of the principal street's peak hour capacity
- Speed and collisions
- Traffic signal level of service
- Volume of traffic on parallel arterials
- Travel times
- Bicycle volumes (Knapp, Chandler et al. (2014)

Stamatiadis, Kirk, et al. (2011) developed guidelines for considering road diet projects, including one showing ranges for operational performance looking at ADT along the main street and side streets:



Chacon-Hurtado, Yang, et al. (2018) discussed a Road Diet tool consisting of a database of 60 case studies. The outputs of the tool yield a number of case studies that match the search criteria in the following input categories:

- Road diet category
- Context or area (suburban, rural, etc.)
- AADT
- Land use

Sohn (2011) introduced a multi-objective genetic algorithm (MOGA) to resolve the network design problem for a road diet (NDPRD). He maintained that the resulting methodology could be used to derive optimal design patterns for road diets. Modeling is also used to evaluate the effectiveness of projects; Empirical Bayes and Full Bayes approaches are most commonly used for before-and-after analyses (Chacon-Hurtado, Yang et al. 2018, Alijamal, Voight et al. 2021). Stamatiadis, Kirk et al. (2011) used simulations performed with the CORridor SIMulation (CORSIM) and VISSIM software as well as the Safety Surrogate Assessment Model (SSAM) to establish required guidelines for road diet conversions.

Road diets have proven to be low-cost options for reducing speeds, increasing safety and allowing better access and mobility for multiple users along many road corridors. As discussed earlier, costs can reduced even further by combining road diets with previously scheduled repaving projects. As a result, most cost/benefit studies show a favorable outcome from road diet conversions. Chacon-Hurtado, Yang et al. (2018) cited a study done on a 2.5 mile corridor of Rainier Ave. in Seattle. The study reported $102.1 million in safety benefits (reduced crash rates) and $32.2 million saved in travel costs over a 20 year period, showing a net benefit of $70 million over that period. Another economic impact tool, the "Tool for Operations – Economic Impact Analysis": (TOPS-EIA) was developed, taking the expected impacts of a strategy on the performance of the corridor, and translating that impact into business cost savings and economic development impacts (Chacon-Hurtado, Yang et al. 2018). Noland, Gao et al (2015) used a VISSIM model to show what they considered to be overwhelming cost benefit over a 20 year period, despite assuming a fairly large decrease in capacity following a conversion. These findings were challenged by Le Vine (2017); while he did not argue whether or not there were cost benefits associated with road diets, he felt that the methodology used by Noland was not appropriate, and that estimates and assumptions used in the model were improperly attained and applied. He expressed the opinion that "transportation planners tend to, on average, systematically under-estimate costs and over-estimate benefits", and went on further to say that Noland's work "does not represent good practice for planning practitioners to follow." Noland (2017) responded to Le Vine's criticism, justifying the methods used and assumptions made.

In conclusion, road diets are most often recommended for their ability to increase the overall safety of the corridor, and to reallocate travel lanes to accommodate multi-modal users. But studies have shown that, when carefully planned and optimized, road diets can be introduced without significant negative effects on the operational facets of traffic along the corridor. In fact, in some cases traffic flow and capacity have actually improved following the conversion. However, there was a general consensus in the studies reviewed for this paper that road diets are not appropriate for all locations, and planners must carefully consider existing conditions and local needs to determine appropriate projects.

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