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TRANSPORTATION BENEFITS AND COSTS OF REDUCING LANE WIDTHS ON URBAN AND RURAL ARTERIALS

Prepared For:

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Research & Innovation Division

Final Report
January 2024

RESEARCH

Keeping Utah Moving

Utah Department of Transportation - Research Division
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DISCLAIMER

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16. Abstract
Reducing the lane width of urban arterials provides space for different street features, whereas selecting the appropriate lane width considering road safety is a concern. The major elements of this research are: a comprehensive literature review investigating the effects narrower travel lanes and other geometric designs have on speed, safety, and other transportation impacts; an in-depth survey of the minimum lane width policies and practices adopted by four leading state DOTs; a survey of AASHTO Committee on Design members regarding their policies and practices, and statistical analyses on speed and crash factors. The authors conducted interviews with five DOTs, and the interviews included queries regarding design criteria, design exceptions, and completed projects or future projects on urban and suburban roadways involving lane width reduction. The findings from the interviews suggest that reducing lane widths contributes to reducing speed and accommodates other modes. However, lane width reductions need to be combined with other low-speed strategies, such as traffic calming and lane repurposing. Enabling integrated walking, biking, transit, and passenger rail can mitigate speed and crash rates. Data from 320 urban and 61 rural arterial sections in Utah were assembled for statistical analysis. Safety modeling showed no direct relation between lane width and crash counts per mile in both areas. However, urban injury crashes are linked to lane width and speed, wider lanes, and higher speeds for increasing injury likelihood. Factors for crash counts were lanes and AADT per lane. This study supports reducing lane widths to enhance road safety and urban transportation infrastructure. Decision makers can use these findings to improve road safety and performance.

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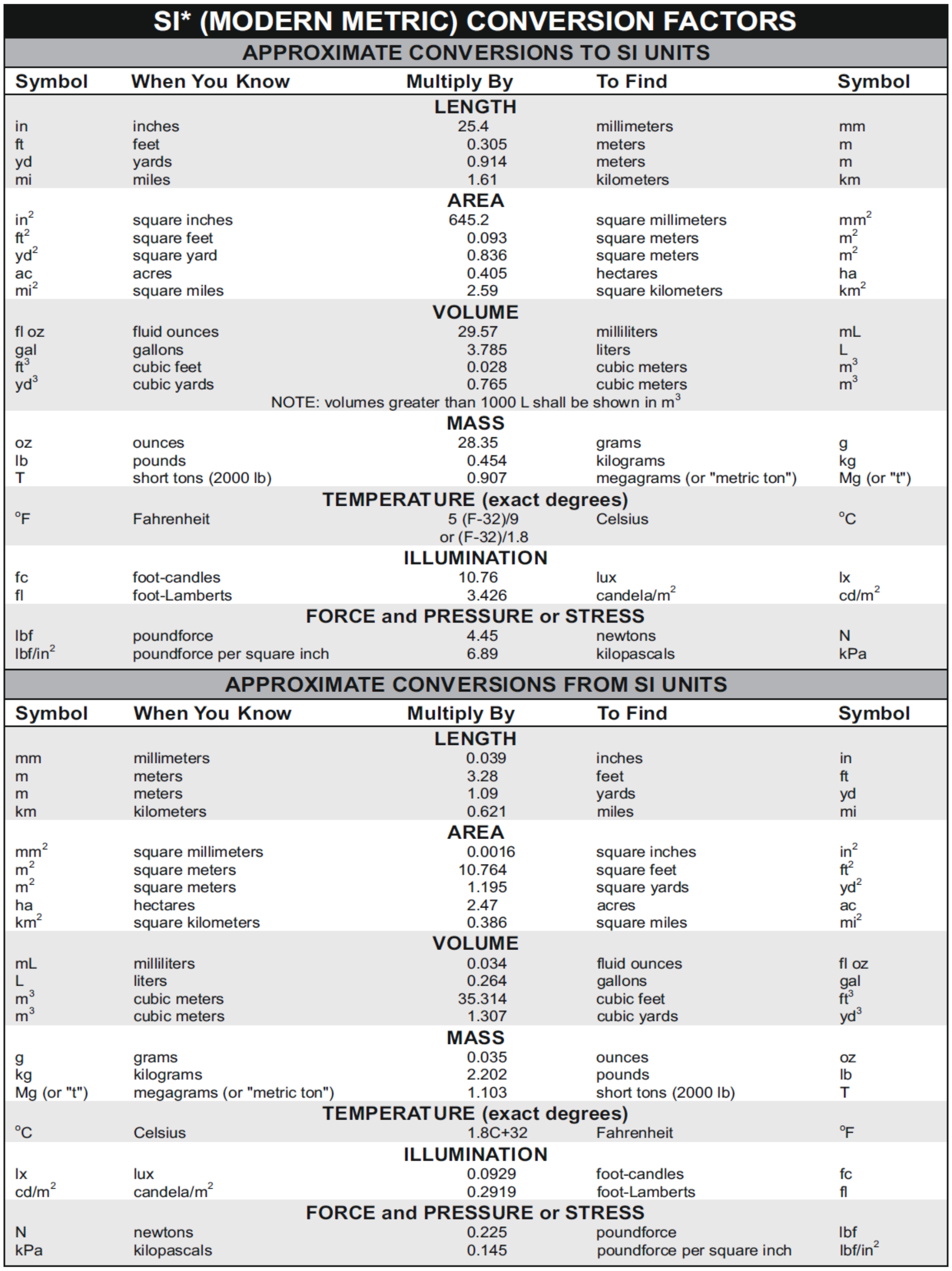
UNIT CONVERSION FACTORS

Units used in this report and not conforming to the UDOT standard unit of measurement (U.S. Customary system) are given below with their U.S. Customary equivalents:



SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. (Adapted from FHWA report template, Revised March 2003)

LIST OF ACRONYMS

DOT	Department of Transportation
UDOT	Utah Department of Transportation
UTA	Utah Transportation Authority
AASHTO	American Association of State Highway and Transportation Officials
VTrans	Vermont Agency of Transportation
ODOT	Oregon Department of Transportation
Caltrans	California Department of Transportation
FDOT	Florida Department of Transportation
DelDOT	Delaware Department of Transportation
AADT	Annual Average Daily Traffic
AADTT	Average Annual Daily Truck Traffic
HDM	Highway Design Manual
NCHRP	National Cooperative Highway Research Program
BUD	Blueprint for Urban Design
VMT	Vehicle Miles Traveled
ITE	Institute of Transportation Engineers
ASCE	American Society of Civil Engineers
NAHB	National Association of Home Builders
ULI	Urban Land Institute
HIV	High Volume Road
LIV	Low Volume Road
FHWA	Federal Highway Administration
FDM	Florida Design Manual
SFS	Speed Feedback Signs

EXECUTIVE SUMMARY

This study consists of four main elements: a comprehensive literature review examining the effects of narrower travel lanes and other geometric design feature on speed, safety, and other transportation impacts; an in-depth survey of the minimum lane width policies and practices adopted by five leading state DOTs; a survey of AASHTO Committee on Design members regarding their policies and practices; and statistical analyses of various factors, including lane width, geometric features, roadside characteristics, block length, and AADT, on 85th and 95th percentile speeds and non-intersection crash counts. The data for analysis were collected for 320 urban arterial sections and 61 rural arterial sections throughout the state of Utah, encompassing all types of UDOT roads.

All four parts of this study consistently support the potential to reduce minimum lane widths in Utah. Our statistical analysis, in particular, suggests that narrowing travel lanes on urban arterials will lead to significant reductions in vehicle speeds without an increase in crash rates. The extra space gained from narrower lanes can be repurposed for bike lanes, wider sidewalks, landscaped medians, pedestrian refuge islands, or parking lanes.

We propose revising the current blanket standard of 12 feet to 11 feet in low-speed, highly urbanized areas, and in special cases, even further to 10 feet. However, our recommendations will include exceptions for urban arterials with heavy truck traffic, following the example set by some other states.

Literature Review

For arterials and collectors (other than freeways), evidence on the effect of lane width on traffic speeds and crash rates is limited and mixed. Some studies show no significant relation between lane width and safety or speed. Others suggest some impact. Narrower lane width assists in traffic calming, and traffic calming measures are sometimes used in combination with narrower lanes to enhance their effect. There are virtually no before-and-after analyses of lane narrowing projects, the ultimate in quasi-experimental research.

Reducing the lane width of arterials provides space for different street features like bike lanes, medians, wider sidewalks, and parking lanes. At the same time, it may also affect vehicle speeds and crash rates. Some studies in rural settings show a significant correlation between collision risk and road characteristics such as the width of the road, lane, shoulder, and medians (Ahmed et al., 2011; P et al., 2009; Zhu et al., 2010; Gårder, 2006), while other studies find no such correlations (Nowakowska, 2010).

Similarly, in urban settings, one study reported that wider lanes and narrower paved shoulders are associated with a decrease in collisions (Dumbaugh, 2006), though other studies found lower crash frequencies on narrower roadways (Hauer et al., 2004; Potts et al., 2007b; Strathman et al., 2001). Manuel et al. (2014) also found a statistically significant positive relation between collisions and segment length but a negative relationship between collisions and roadway width.

NCHRP Report 330 investigated the effective utilization of street width of urban arterials with speed limits of 45 mph or less. This study suggests that lane widths narrower than 11 feet can be used effectively on urban arterials. Moreover, 10-foot lanes are widely accepted with reduced or unchanged crash rates. However, it was also suggested that a lane width of less than 10 feet should be used cautiously, considering the safety implications. That same study found no consensus in the literature regarding the relationship between lane width and speed, despite speed being a critical factor in crashes.

Another study declared the threshold for safer roads as 11 feet and showed that wider lane widths are not associated with greater road safety (Hauer, 2000). According to Dumbaugh (2000), 11-foot lanes have 11 percent fewer mid-block crashes than streets with 12.5-foot lanes, and more for injury and fatal crashes. Higher crash rates on wider roadways are believed to occur due to an increased but false sense of safety.

Besides lane width, road geometric design features such as segment length, roadway curvature, roadside development, type of traffic control, access-point density, and midblock change positively impact collisions (Manuel et al., 2014; Dumbaugh, 2000). In addition, roadside features, including street trees and side parking, have been shown to play a significant role in controlling traffic and giving drivers a different perspective on speed and safety. Overall, the literature review suggests the need for additional studies to provide clearer insights into the effects of lane widths on safety and speed, the latter being a particularly under researched topic.

Exemplary State DOT Standards and Guidelines

As part of the project, we reached out to five state Departments of Transportation (DOT) and interviewed individuals who possess adequate knowledge in regard to lane width reduction or road diet projects either currently underway or recently conducted by the organization - Vermont Agency of Transportation (VTrans), Oregon Department of Transportation (ODOT), California Department of Transportation (Caltrans), Florida Department of Transportation (FDOT), and Delaware Department of Transportation (DelDOT). The five DOT organizations were selected based on their relatively progressive though different approaches to setting and managing travel lane widths, each deviating from the standard blanket state-DOT-dictated 12-foot width. All five DOT organizations interviewed for the project allow for travel lane widths of 10 or 11 feet in urban contexts, with VTrans setting the minimum as low as 9 feet (for collectors).

Following the logic described in the previous paragraph and based on its own research titled "Integrating Transit into Traditional Neighborhood Design Policies – The Influence of Lane Width on Bus Safety," in 2014, Florida Department of Transportation modified the criteria for Urban Arterial Travel Lane Width and established 11-foot travel lanes for roadways with a divided typical section in or within one mile of an urban area and with a design speed of 45 mph or less. In 2018, FDOT introduced context-based design speeds - appropriate lane widths are selected for target speeds within each design context (natural, rural, rural town, suburban, urban general, urban center, urban core). Under urban low speed conditions, 10-foot lanes are desirable, and the use of wider lanes must be justified. In rural conditions, 11-foot lanes are treated as standard, and the use of narrower lanes must be justified. Lanes cannot be less than 10 feet wide. *"What we found was that in the urban conditions, the lane width really was not a factor for safety,"* explains DeWayne Carver, State Complete Streets Program Manager (FDOT).

Vermont State Design Standards, adopted in 1997, set lane widths for urban and village both principal and minor arterials at 10 to 12 feet, depending on specific settings. The 10-foot widths are suggested for highly restricted areas with little or no truck traffic, while the 11-foot lanes are to be used extensively for urban and village principal arterial street designs. The 12-foot lane widths are generally proposed for all higher speed, free-flowing principal arterials. For two-lane rural principal arterials, the minimum lane width is set at 11 feet for speeds of 50 mph and below, and at 12 feet for speeds 55 mph and above. The minimum lane width for minor rural principal arterials is set at 11 feet for all speeds.

Vermont State Design Standards allow for 9-foot-wide lanes on urban and village collectors in highly restricted areas with little or no truck traffic, and on rural collectors at all speeds with projected design traffic volume below 1500 ADT. The use of 9-foot lanes, which are sub-AASHTO guideline, was legislatively authorized when tort liability was waived by statute.

In Oregon, lane widths and other road design standards are provided by the Blueprint for Urban Design (BUD) which was created in 2020. In 2023, the BUD was combined with the ODOT Highway Design Manual (HDM). The BUD provides detailed design guidelines for six urban contexts: Traditional Downtown/Central Business District, Urban Mix, Commercial Corridor, Residential Corridor, Suburban Fringe, and Rural Community. The recommended travel lane width is between 11 and 12 feet for all contexts but the Traditional Downtown/CBD context, where the recommended width is 11 feet. However, lane widths of 10 feet are allowed but require design exceptions: "*We didn't go to 10 as a part of the range at the outset. Our chief engineer is not opposed to 10-foot lanes but doesn't want to have that as a flexibility option to just use. If you want to do a 10-foot lane, we would do that with a design exception based on appropriateness and based on route needs in those locations.*" (Rich Crossler-Laird, Senior Urban Design Engineer at ODOT).

ODOT's situation is unique as its design guidelines must take into consideration interests of widely defined freight interest groups: the trucking industry, mobile home manufacturers, oversize load freight, general contractors, and paving contractors (accommodations for 18-foot-wide, 245 feet long, up to million-pound vehicles). "*When we looked at the Blueprint for Urban Design, we wholeheartedly wanted to reduce our lane widths as much as possible, but we don't always find the ability to do that. This depends on what we can do to accommodate those other freight. Even when putting in a six-inch-high raised curb median, we have to discuss it with our freight partners in how that's going to affect their ability to get freight through from a commerce* *standpoint and economic standpoint*." (Rich Crossler-Laird, Senior Urban Design Engineer at Oregon Department of Transportation)

In California, lane width standards are set by the Highway Design Manual which was most recently revised in 2020. In general, the minimum lane width is set at 12 feet, however the Manual also provides a few exceptions to this rule. The minimum lane width of 11 feet is allowed for conventional state highways in urban, city or town centers with posted speeds less than or equal to 40 mph and AADTT (truck volume) less than 250 per lane. Even though the preferred lane width is 12 feet, narrower travel lanes (10-11 feet wide) are frequently achieved through road repurposing and redesign projects which always require design exceptions. Travel lanes are on such occasions narrowed from 12 feet to 10 or 11 feet in order to provide for bike lanes.

For Delaware, the Delaware Road Design Manual sets lane width standards between 10 and 12 feet depending on design speeds. It states that 12-foot lanes should be used on roadways with design speeds of 55 mph or greater, 11-foot travel lanes on roadways with design speeds from 35 mph to 50 mph, and 10-foot travel lanes on roadways with design speeds below 35 mph with consideration for 11-foot lanes that are adjacent to bike lanes. The manual further suggests that 10-foot travel lanes should also be avoided along transit routes and roadways with heavy truck traffic. Currently, a 12-foot lane is considered a default standard, with 11-foot and 10-foot lanes seen as "acceptable" under specific conditions. However, DelDOT is in the process of releasing its new road design manual that will set the default lane width at 11 feet. Engineers at DelDOT believe there is no significant difference in traffic operational parameters, including crash and speed, between 11- and 12-foot lanes. Also, from the driver's perspective, there is no noticeable difference with a 1-foot lane width reduction. During the interview it was noted that "*No complaints were ever submitted on having 'too narrow' lanes.*"

Best Practice Review

Even though the standard travel lane width prescribed by the AASHTO Green Book is 12 feet, the AASHTO Green Book makes allowances for 11-foot-wide lanes for design speeds of 45 mph or less and even suggests that such width might be advantageous under certain conditions. The Highway Safety Manual, likewise, states that evaluation of the effects of travel lane widths of

10 to 12 feet on crashes for urban arterial roadways has found no general indication that using narrower widths within this range increases crash rates (neither high truck traffic nor bus traffic was quantified in this research).

Based on other best practice guides and manuals, depending on other roadway elements, the common recommended lane width is 11 or 12 feet in urban and rural areas. Lower functional classes typically allow narrower lane widths. Urban areas, particularly the most urbanized portions of urban areas, tend to have lower recommended lane widths than rural areas. Lower-speed roads also tend to have 11-foot lanes, or even 10-foot lanes in certain cases. In roadways with higher truck volumes, AADT, and average speed, lane width is mainly set at 12 feet. A lane width of 9 feet can be applied to local roads only.

However, various design exceptions are recommended frequently. For posted speeds less than 35 mph, narrower lane width (less than 11 feet) can be used. Design exceptions mainly apply to lane widths less than 11 feet. Horizontal curves might require wider lanes due to off-tracking of larger vehicles, depending on traffic and speed. Depending on roadway ownership and management, design exceptions must go through different processes.

AASHTO Committee on Design Survey

Our team surveyed the American Association of State Highway and Transportation Officials (AASHTO) design committee members to identify successful lane width reduction projects in the United States and their impacts on traffic safety, vehicle speed, and vehicle and pedestrian volumes.

The survey results indicated that improving safety was the primary goal of minimum lane width policies and lane reduction guidelines. All 13 individual respondents have statewide roadway design standards, manuals, and policies that regulate vehicle lane widths.

Respondents specified their agencies' goals of having minimum lane width policies and lane reduction guidelines. Improving traffic safety (92.3%) and safety for pedestrians and bicycles (69.2%) ranked at the top, followed by reducing vehicle speed and promoting multimodal transportation.

In order to implement a design exception process allowing lane width reduction, specific road or environmental conditions are required, including factors such as roadway classification, speed, traffic volume, functional class, zoning, context (urban or rural), and others.

The overall impressions of respondents about lane width reduction projects can be summarized as follows: 33.3% believed that these projects improve traffic safety and reduce vehicle speeds, while another 33.3% mentioned their influence on construction and maintenance costs. Others confirm significant bicycle and pedestrian activity changes and reduced congestion (11.1% each).

However, the observed/measured safety impacts differed from their overall impressions. Most respondents (66.7%) expressed uncertainty about the safety impacts of lane width reduction. Only 11.1% of respondents had observed decreased rates of crashes and crash severity. In addition, more than half of respondents are unclear about changes in traffic volume, pedestrian and bicyclist volume, and construction/maintenance costs after reducing lane widths.

The physical changes resulting from lane width reduction in cross-sectional road design were evident. The most implemented physical change to the road cross-sectional designs was pedestrian refuge islands (57.1%), closely followed by the expansion of pedestrian sidewalks and multimodal transportation infrastructure (42.9%). In addition, on-street parking and traffic calming were identified (28.6%) as purposes for lane narrowing.

Despite the interests and expectations regarding lane width reduction projects, members of the AASHTO design committee have no clear evidence of the observed/measured impacts of reducing lane width.

Quantitative Analysis of Lane Width vs. Vehicle Speed and Crash Frequency for UDOT Arterials

The quantitative analysis of this part of the project was to determine the impact of lane width on the speed and safety performance of UDOT arterials. The modeling started by examining the statistics of lane width and the initial relationship between lane width and other road variables. As roadway classification can affect operational performance, the modeling was conducted separately for urban and rural arterials. The frequency distribution shows that most UDOT arterials have a lane width between 11 to 12 feet, which is consistent with the minimum lane width of 12 feet set by UDOT's *Roadway Design Manual*. Some are as wide as 14 feet or even 15 feet. Therefore, we were interested in investigating the effect of reducing the lane width to 11 feet or less on the speed and safety of arterials.

Initially, a scatterplot of lane width versus 85th percentile speed suggested an upward-sloping relation between the two, indicating that narrower lanes tend to have lower speeds. However, in urban areas, the simple correlation coefficient approaches but does not quite reach statistical significance at the 0.05 level. The same results were found by looking at the nonlinear relationship between lane width and speed, indicating a positive relationship between the two yet not a significant one.

Speed models were developed using linear regression, and the most significant variables were identified by testing them to determine their sign and significance level. The results showed that the lane width does impact speed on urban arterials, particularly at the upper end of the speed range. Controlling for other variables, *each additional foot of lane width* leads to an *increase in both the 85th percentile speed and the 95th percentile speed of more than 1 mph.* The difference between a roadway with 14-foot lanes and 10-foot lanes would be more than 4 mph.

Lane width was also found to be significant in rural areas, where narrower lanes can reduce speed. The coefficient of lane width suggests that, controlling for other variables, *an additional foot of lane width in rural areas can increase 85th percentile speed by 3.9 mph*. It is worth noting that for urban arterials, other variables, including the number of lanes, a non-traversable median, on-street parking density, roadside objects, and average block length, also affect 85th percentile speeds. Other significant variables for rural arterials were found to be average block length and the presence of a sidewalk (representing development along the roadway).

The safety modeling process also began by examining the distribution of total crash counts and injury crash counts. Modeling fatal crashes was skipped because there are insufficient cases with fatal crashes in the collected dataset (only 3 percent of roadway segments experienced a fatality in 2021). *Total* crash counts per mile are not related to lane width directly or indirectly through the 85th percentile speed in either urban or rural areas. Apparently minor fender-bender crashes on narrow, low speed roadways offset more serious crashes on wide, high-speed roadways.

In contrast, on urban arterials, more serious *injury* crash counts are related to both lane width and 85th percentile speeds. The relationships appear in a hurdle model, used when a frequency distribution has an excessive number of zero values (zero inflation), as does the frequency of injury crashes. Specifically, the occurrence of any injury crash on an urban arterial is positively related to lane width, both directly and indirectly through the 85th percentile speed. Controlling for other variables, *a one-foot increase in lane width is accompanied by a 38.3 percent increase in the odds of a roadway section having an injury crash*. Also, controlling for other variables, *a one-mph increase in the 85th percentile speed is associated with a 4.7 percent increase in the odds of an injury crash*. However, the exact number of injury crashes (if there are any) is not related to either variable. The only other variables that proved consistently significant are number of travel lanes and AADT per lane in thousands, both with positive relationships to total and injury crash counts.

The results of the rural area modeling were inconclusive perhaps due to our small sample of rural arterials. The results indicate that only the number of lanes and AADT per lane in thousands proved significantly associated with the total crash counts and injury crash counts. No other variables, including lane width and 85th percentile speed, significantly impacted positive crash counts.

1.0 INTRODUCTION

Reducing vehicle lane widths is often considered a way to decrease vehicle speed and increase road safety. According to the comprehensive street design guide jointly published by the American Society of Civil Engineers (ASCE), the National Association of Home Builders (NAHB), the Urban Land Institute (ULI), and the Institute of Transportation Engineers (ITE), "designers should select the minimum lane width that could reasonably satisfy all realistic needs, thereby minimizing construction and maintenance costs, while at the same time maximizing livability of the community." This approach is also likely to provide more space for active transportation infrastructure.

However, there are also concerns about narrower travel lanes. Reduction in lane width might result in lower travel speed and, consequently, affect road capacity. Redesigning the existing roads would involve costs for construction and maintenance. Moreover, whether reducing lane widths would result in safer streets has not been fully understood, and the research findings to date are mixed. An early study documented that decreased vehicle lane widths of residential streets are safer in injury crash occurrences (Swift et al., 1997). However, more recent articles found that the relationships can vary depending on the traffic volumes of examined roads. In particular, narrower vehicle lane widths were found safer on rural roads, whereas narrower lane widths were found more dangerous on highways or urban arterials segments (Abdel-Rahim & Sonnen, 2012; Pokorny et al., 2020; Rahman et al., 2018; Rista et al., 2018). Therefore, understanding the various costs and benefits of vehicle lane width changes is essential to promote successful road designs. Nevertheless, in Utah, comprehensive research is lacking that gauges the effects of traffic lane widths on relevant transportation performance measures, such as road safety, city, pedestrian traffic volume, and agency cost.

Our research objective is to examine the transportation effects of vehicle lane widths on urban and rural arterials in Utah regarding road safety, highway capacity, pedestrian traffic volume, and agency cost. While controlling for other influences, such as land use characteristics, shoulder widths, and other cross-sectional road design elements, we empirically measure how much and in which direction selected transportation variables—all/injury crash rates, vehicle speed, vehicle traffic volumes, pedestrian counts, and road construction/maintenance costs—

change with lane widths of urban and rural arterials. This research will find optimal lane widths that promote road safety and capacity, increase walkability, and minimize construction/maintenance costs for urban and rural arterials in Utah. Moreover, using the research findings and a complete dataset of cross-sectional road design elements (e.g., total lane width, total shoulder width, number of lanes, etc.), we will find priority areas for lane width adjustment projects and suggest potential design improvements. We believe our research will increase our understanding of road design elements and their relations to transportation benefits and costs and inform evidence-driven transportation practices.

With the collection and processing of data related to safety (e.g., all/ injury crash rates), highway capacity, pedestrian traffic volume, and agency cost (i.e., maintenance and construction costs), we can have a better understanding of the current practice, opportunities, and challenges in road width design. Further, the availability of design guidance for the state would greatly benefit Utah residents. For example, due to the high traffic volumes, Dr. Yang's UTRAC project UT-19.26 showed crash risks in small towns along state highways. The reduced speed on narrow roads may improve traffic safety in those places. Moreover, constructing narrow roads can improve life quality by creating more active transportation opportunities.

This research could support many regional and local planning efforts for safe and activity-friendly Wasatch Front roads. Our research will compile a complete dataset of cross-sectional road design elements for all Utah urban and rural arterials and find optimal lane widths that promote road safety. Relating to UDOT's Zero Fatalities goal and Salt Lake City's Community Livability Projects (also called traffic calming), the dataset and research findings we produce will help policymakers identify areas for roadway reconfigurations. It can also facilitate roadway design improvements for multi-modal mobility, such as pedestrian refuge islands, transit shelters, bicycle lanes, on-street parking, or traffic calming measures.

The increased opportunities for active transportation facilities can be connected to the existing walking and bicycling networks of many localities and contribute to enhancing community livability, public health, and economic development. Also, the findings of this study can directly be incorporated into UDOT's Highway Safety Improvement program (especially non-infrastructure projects such as crash prediction models), as well as the Transportation Alternatives program to improve roads and intersections at the local level. The study results will help to prioritize segments that need lane width adjustment, which can then be integrated with UDOT’s Reconstruction, High Volume Road (HIV), and Low Volume Road (LIV) programs. Last, but not least, the results will help UDOT more efficiently implement the Spot Safety Improvement program, which funds infrastructure and non-infrastructure projects that are expected to reduce traffic fatalities and serious injuries significantly.

2.0 LITERATURE REVIEW

2.1 Safety

2.1.1. Lane Width

Reducing lane width on urban arterials seems beneficial for providing more space to include other street features such as bicycle lanes, on-street parking, wider sidewalks, landscaped buffers, and reducing pedestrian crossing distances. However, safety is a critical concern in selecting appropriate lane widths on urban arterial roads. The results of past studies on the relationship between safety and lane width of urban arterials are varied (Manuel et al., 2014; Potts et al., 2007a).

Lane width in urban and rural settings may have different impacts on safety. In rural settings, some studies reported a significant correlation between collision risk and characteristics associated with road widths, such as the number and width of lanes and shoulder and median widths (Ahmed et al., 2011; P et al., 2009; Zhu et al., 2010). In contrast, another study found lane width and shoulder width are insignificant factors in crash severity, explaining that this might be due to the significant impact of shoulder type on roadway safety that contributes a 30-70% collision reduction (Nowakowska, 2010). This finding contrasts with an earlier study of two-lane rural highways finding that wider shoulders promote higher crash severities (Gårder, 2006).

Similarly, in the context of urban areas, the findings of different studies are inconsistent regarding the relationship between lane width and safety. A study of nonfreeway urban roads found that wider vehicle lanes and narrower paved shoulders are associated with decreases in both roadside and midblock collisions (Dumbaugh, 2006), while several other studies of urban roadways reported that narrower roadways had lower crash frequencies (Hauer et al., 2004; Potts et al., 2007b; Strathman et al., 2001).

In another study by Manuel et al. (2014), the effect of road width on urban collector roadways was examined by developing negative binomial (NB) safety performance functions (SPFs). The study found that segment length, traffic volume, access-point density, and midblock change were statistically significant and positively related to collisions, while the roadway width was negatively and statistically significantly related.

In addition to lane width and other factors influencing speed such as roadway curvature, roadside development, and type of traffic control, an earlier study listed two major methods to quantify this relationship in a quasi-experiment study (before and after) of a single roadway segment and studies of several roadways with various lane widths (Parsons Transportation Group, 2003). The study found no consensus among literature focusing on lane width's relationship to speed.

In NCHRP Report 330, Douglas Harwood (1990) investigated the effective utilization of street width on urban arterials at 35 sites located in five states. More specifically, he focused on the effectiveness of various alternatives for the use of streets within the same curb-to-curb width. He controlled for factors with potential impact on effectiveness, including traffic volume, vehicle mix, capacity (level of service), prevailing speeds, alignment (cross section), development type, and access to adjacent property. Harwood's study was limited to urban arterials with a speed limit of 45 mph or less. The study's conclusion is based on lane width:

- Lane width narrower than 11 feet can be used effectively for urban arterial improvements, while narrower lanes may result in some accident types
- 10-foot lane width is widely accepted by engineers with reduced or unchanged accident rates.
- A lane width of less than 10 feet should be used cautiously based on its impact on the accident rate.

Roadside features, including street trees and side parking, have been shown to play a significant role in controlling traffic and giving drivers a perspective of spatial layout. However, the location of roadside obstacles and their visibility are important in road safety. Besides having a safe zone for roadside features, other geometric designs are associated with the safety of roads (Dumbaugh, 2000). Among these, lane width is one of the features that can improve safety. Hauer has shown in a study that wide lane widths are not associated with safety and declares that the threshold for safer roads is 11 feet (Hauer, 2000). Dumbaugh (2000) has shown that 11-foot lanes tend to have 11% fewer mid-block crashes compared to streets with 12.5-foot lanes. This comparison is substantially more significant in injurious and fatal crashes. The main contributor to improved safety is believed to be the driver's "reading" of the road environment and acting on corresponding hazards. The explanation of higher crashes in wider roadways is explained as:

> "*The purpose of features such as wider lanes and clear zones would appear to reduce the driver's perception of risk, giving them an increased but false sense of security, and thereby encouraging them to engage in behaviors that increase their likelihood of being involved in a crash."*

It is suggested that design parameters should be based on "drivers' perception of risk" rather than engineering principles. For instance, in roadways, when the perception of safe speed is higher than the posted speed limit, drivers tend to drive faster than the designated speed. Besides this, road design elements and other traffic calming measures can also be effective in the safe operation of roadways.

2.1.2. Shoulders

One of the critical variables that influences crashes is the shoulder. Roads with shoulders can indirectly influence crash frequencies by affecting average vehicle speed (Bobermin et al., 2021; Ewan et al., 2016; Gargoum & El-Basyouny, 2016). This suggests that the presence of shoulder lanes may increase vehicle speeds, which, in turn, produces higher crash frequencies. Removing or narrowing shoulder lanes is likely a more effective way of managing speeds and, consequently, reducing collisions, than is narrowing lane widths (Gargoum & El-Basyouny, 2016).

Directly, increasing shoulder width is positively associated with higher crash rates (Bamzai et al., 2011; Ewan et al., 2016). For example, Bamzai et al. (2011) pointed out that shoulders that are narrower than 2.44 meters potentially decreased shoulder-related crashes. Furthermore, Gitelman et al. (2019) found that an increase in the width of unpaved shoulders beyond 0.9 meters increased crash risk, specifically injury and total crashes, increasing by 5% for each 0.1 meter of shoulder extension. However, the lowest crash risks occurred for total shoulder widths of approximately 3m or wider and narrow total shoulders below 1 meter.

On the other hand, another body of literature found that roads with shoulders are likely to have lower crash frequencies (Arévalo-Támara et al., 2020; Gitelman et al., 2019; Gross & Jovanis, 2007). According to Gitelman et al. (2019), there was an increase in crash risk associated with an initial extension of the total shoulder by up to 2.2 meters. However, when the shoulder was further widened beyond 2.2 meters, there was a consequent decrease in crashes. Moreover, a driving simulation study consistently suggested that the presence of shoulders could reduce head-on collisions. This is because drivers tend to drive farther from the traffic in the opposite direction (Bobermin et al., 2021).

2.1.3. Number of Lanes

Previous studies also confirmed that the number of lanes significantly impacts road safety (Abdel-Aty & Radwan, 2000; Council & Stewart, 1999; Milton & Mannering, 1998). Milton & Mannering (1998) observed that the number of crashes in rural areas of Washington State increased with the number of lanes. Furthermore, Abdel-Aty & Radwan (2000) confirmed that crash rates increased as the number of lanes on urban road sections increased. A higher number of lanes is likely associated with frequent lane changes, which may increase vehicle conflicts and lead to more crashes (Milton & Mannering, 1998).

On the contrary, other literature suggests that roads with more than two lanes produce lower crash counts for all crash levels of severity (Ma & Kockelman, 2006; Park et al., 2010). One possible explanation for this is that wider roads provide more room for avoiding crashes in situations that are prone to them (Imprialou et al., 2016). Another explanation for this result is that it considers crashes that occur on undivided, single carriageways. Over half of the analyzed crashes occurred on A-roads, including some single carriageways, which are associated with risky vehicle interactions that can result in severe crashes, such as head-on collisions (Imprialou et al., 2016).

2.1.4. Parking

On-street parking is another variable that can impact crash frequency. It is highly correlated with average speeds and, consequently, crash frequency. On-street parking provides safe environments, as identified by Dumbaugh & Gattis (2005), finding that 11% fewer crashes occurred on a livable street with high roadside activities, including on-street parking, than in a comparison road section. The author attributed this to drivers' consciousness when driving through a crowded area, causing fewer collisions.

On-street parking serves two main functions: as a traffic calming tool and as a buffer separating pedestrian activities from vehicle traffic (Biswas et al., 2017). Previous studies have shown the function of on-street parking as a traffic calming measure, but its application is limited only to corridors with speed limits of 40 kph or less (Duany, 1990). In addition, on-street parking acts as a buffer between vehicle traffic and pedestrians, making them feel more secure and relaxed and creating a safe environment (De Cerreño, 2004; Ossenbruggen et al., 2001). On-street parking protects bicyclists against high-speed vehicle traffic while reducing bicycle crashes (Søren & Jensen, 2007).

On the other hand, road segments with one-sided or two-sided parking show a higher risk of pedestrian-vehicle crashes than without on-street parking under specific road conditions (Dumbaugh & Gattis, 2005; Hauer et al., 2004; Kraidi & Evdorides, 2020). In a complex urban setting, a higher risk of pedestrian-vehicle crashes is mainly due to driver behavior caused by parked vehicles on the street. On roads with parked cars, drivers typically face higher levels of stress, reduce their speed, and position their vehicle farther from the centerline to avoid oncoming traffic (Edquist et al., 2012). Furthermore, a review study by Biswas et al. (2017) concluded that the effects of on-street parking vary depending on the road category. For major streets, on-street parking is strictly unsafe. The study also argued that on-street parking should be restricted around some specific locations, such as designated pedestrian crossings and intersections. On the other hand, parallel parking, not angled, can be allowed on minor streets where less traffic travels at lower speeds.

2.1.5. Enclosure

In urban design, the blockage of sky visible ahead in a given area is commonly referred to as the degree of street “enclosure." Street enclosure is the collective effect of large objects surrounding a street, buildings, and trees to define the spatial extent of a streetscape and restrict long sight lines (Harvey & Aultman-Hall, 2015).

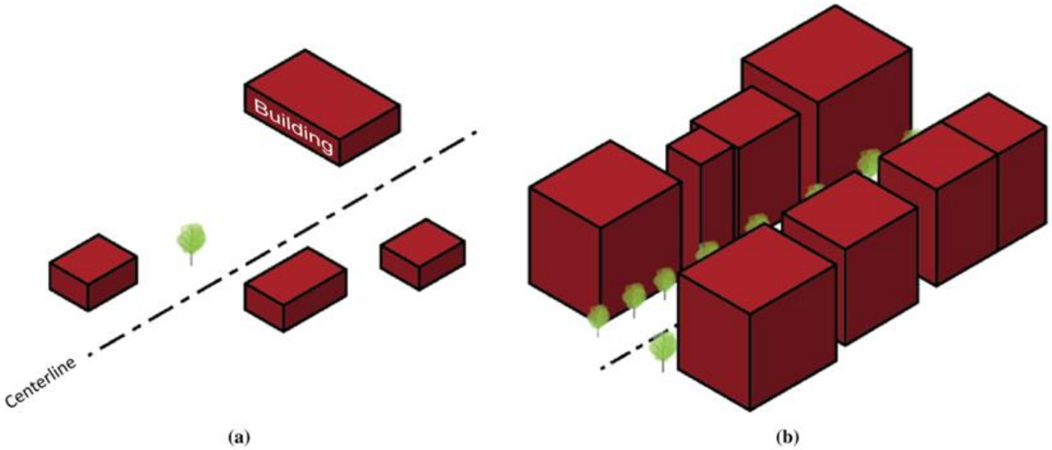


Figure 2-1 Example of Open Streetscape (a) and Enclosed Streetscape (b) (Sourced from Harvey & Aultman-Hall, 2015)

According to Harvey & Aultman-Hall (2015), more open-view streetscapes with less enclosure tend to encourage higher speeds and riskier driving behavior, thereby causing more traffic crashes, especially on urban arterials. Conversely, certain landscapes or objects on the roadsides are often regarded as unpleasant and visual clutter, which may lead to collisions, injuries, and fatalities (Moradi et al., 2019; Young & Salmon, 2012).

In terms of severity, crashes in urban contexts are less likely to be severe when they take place in smaller, more enclosed streetscapes. Drivers likely operate vehicles at slower speeds when their vision is more constrained by smaller or more enclosed spaces, especially in urban settings with complex traffic patterns and diverse road users (Naderi, 2003). This suggests that rather than assuming that dense and complex urban roadside environments reduce traffic safety, traffic safety along urban arterials largely depends on encouraging drivers to maintain moderate speeds and avoid risky behavior within enclosed streetscapes.

The urban design quality of enclosure refers to a street or other types of public spaces defined by vertical elements such as unbroken lines of buildings, walls, and trees that create a sense of an enclosed space, a room-like quality (Ewing and Handy 2009). Operational definitions of urban design qualities developed by Ewing and Handy (2009) defined enclosure by the proportion of street wall on both sides of the street segment, the proportion of sky ahead and across in addition to the long sight lines.

There is another possible connection between the roadside environment and speed of travel in an automobile, posited first by Don Appleyard and co-authors back in 1965 (The View From the Road). If objects such as trees, buildings, and parked cars are close to a driver, they provide the driver with reference points to judge how fast they are moving, which tends to slow them down. If the same fixed objects are set far back from the road, drivers lack reference points and are more likely to speed. This is a common experience of drivers on freeways, particularly in rural areas. *"Beyond the concentration on near detail, the fundamental sensation of the road, continually referred to, is the visual sense of motion and space. This includes the sense of motion of self, the apparent motion of surrounding objects, and the shape of the space being moved through. These factors are all intertwined, since the visual judgment of motion is based on the apparent motion of exterior objects and is interpreted as being motion in relation to the enclosing spatial form."* (p. 8).

2.2. Capacity and Speed

Several studies investigated the relationship between lane width and other geometric features and saturation flow rates (Potts et al., 2007; Shao et al., 2011; Susilo and Solihin, 2011; Bester and Meyers, 2007; Le et al., 2000; Chen et al., 2011). Many studies found a positive association between lane width and saturation flow rates (Potts et al., 2007; Shao et al., 2011; Susilo and Solihin, 2011), while some other studies suggested a range of saturation flow values for different lane widths (Cobbe, 1966; Sarna and Malhotra, 1967; Miller, 1969). Shao et al. (2011) developed a simple saturation flow model between lane width, saturation flow, and curve radius and found an increase in saturation flow when lane width and curve radius increase.

In a study by Choudhury (Choudhury, 2004), the effect of lane width on roadway capacity is estimated using field data. Based on the results, the capacity and carriageway width follows a second-degree curve. Also, it was shown that effective lane width is affected by shoulder conditions and can impact roadway capacity. It is mentioned in a previous Highway Capacity Manual (HCM 5th edition) that a reduction of lane width by 1 foot at signalized intersections will reduce capacity by 3.33%; however, for lanes less than 10 feet in width, there is no significant capacity reduction (Petritsch, 2009). However, according to the HCM seventh edition, for a lane narrower than 12 ft and a shoulder narrower than 6 ft, the speed is reduced for the two-lane highways (NASEM and TRB, 2022)

Since the saturation flow rate is influenced by lane width, a study by Potts et al. (2007c) investigates the actual saturation flow rates at signalized intersections compared to the HCM estimation. The statistical analysis between lane width and average saturation flow rate demonstrated results as below:

1. 9.5-foot lanes compared to 11- and 12-foot lanes have 4.3% lower saturation flow rates,
2. 11- or 12-foot lanes have 4.3 to 4.4 % lower saturation flow rates compared to 13-foot lanes.

Results of this study indicated that actual saturation flow rates are generally lower than values suggested by the HCM (5th edition). It is worth noting that besides actual lane width, side friction factors, including but not limited to parking, pedestrian, and bus stops, play a significant role in road capacity and average speed. A recent study by (Patkar and Dhamaniya, 2019) has shown a linear relationship between increased side friction factors and reduced effective lane width and capacity correspondingly. Similarly, it was observed that stream speed would be reduced. Later, it was shown that a 3.2% capacity reduction followed a 2% increase in side friction factors (Gulivindala and Mehar, 2020).

Reviewing the literature on the relation between lane width and speed, most studies suggest no significant relationship between the two. Even though narrower lanes (9 ft) experience a lower average speed than 10-foot lanes, the difference is insignificant. However, narrower lanes will reduce lateral movements that, as a result, increase safety. On the side, road marking and medians can also affect drivers' perceived lane width and driving speed. These factors are more influential on curves than straight road segments (Godley et al., 2004).

2.3. Pedestrian Volume

The discussion of lane width and its impact on pedestrian volume is loosely examined at the current stage. However, we could identify that pedestrian volume is more actively discussed with the number of lanes concerned with a road diet. Many local, regional, and state agencies have considered road diet accommodating multiple travel modes compared to traditional roadway design by reducing vehicular traffic lanes and reallocating right-of-way for other modes. A road diet typically refers to a low-cost safety solution for a roadway where average daily traffic is

25,000 or less, converting an existing four-lane undivided roadway into a three-lane roadway consisting of one lane in each direction and a center two-way left-turn lane (FHWA, 2010). The excess width in dropping a lane can be used for bike lanes or wider sidewalks. Many studies have attempted to estimate the impact of a road diet on pedestrian volumes. The results of most studies indicated that the pedestrian volume significantly increased after the road diet projects.

Gudz et al. (2016) explored changes in bicycle and pedestrian volumes after the road diet project in Davis, California. The number of bicyclists increased by 243% at a statistically significant level after the road diet, while pedestrian counts showed a minor decline that was not statistically significant. In another study, Ntonifor (2017) analyzed the changes in pedestrian volume along a segment of Wilson Blvd in Arlington County, Virginia, before and after the implementation of the road diet project reducing travel lanes from 4 to 2 with a two-way center left-turn lane. The before-and-after counts were investigated during AM and PM peak hours, where frequent complaints were received from users. The analysis of pedestrian volume slightly decreased compared to other traffic characteristics such as traffic volume, travel time, and speed.

On the other hand, not surprisingly, the bike volume significantly increased after the road diet, mainly due to the addition of bike lanes on the road. Anderson and Searfoss (2015) identified the changes in pedestrian volume by studying the case of Orlando, Florida. Pedestrian volume decreased by 23 percent at the intersections during peak hours, while bicycle counts surged by 30 percent. This result corresponds to the findings of Ntonifor (2017). Yet, different directional results from the road diet project in New York showed that pedestrian volume increased after the 4th Avenue, Sunset Park Traffic Calming project. This project adjusted optimal lane width and widened medians at intersections to allow safer pedestrian crossings.

No studies have attempted to find the relationship between lane width and pedestrian volume. Though one study explored the effects of adjusting lane width and widening median width, it is still not enough to clearly say that there is a relationship between lane width and pedestrian volume. Therefore, studies on the relationship between lane width and pedestrian volume are necessary to improve pedestrian safety on roadways.

2.4. Agency Costs

The costs saved by narrowing lanes depend highly on project location, purpose, and network. Petritsch (2009) notes that reducing lane width generally costs less, as less material and land are required, and other items, including right-of-way, utility easement, and construction costs, are reduced. From an optimizing costs perspective, it is observed that minimum lane width has the least construction and maintenance costs and is suggested to be employed in design standards (Chen et al., 2020). In addition, the analysis of agency cost to user cost shows 12-foot lanes to be higher than 1.0 for major rural collectors, showing the significance of agency costs for design departments (Labi et al., 2017). However, based on shoulder width, smaller lane width can be chosen to maintain the balance between agency costs and user costs.

Using the lane widening project auction data from UDOT, an estimate of these projects' costs shows that the average construction cost would be between 3 to 4 million dollars. By looking further into items involved in these projects, it can be concluded that reducing lane width is proportional, and aggregated agency costs are reduced. However, there is no literature specifically on the costs of lane reduction projects, and the latest conclusion is based on observed trends and typical predicted costs. Further, no quantitative analyses of agency costs were available based on interviews with multiple DOTs in other states.

<u>3.0 SELECTIVE STATE DOT STANDARDS AND GUIDELINES</u>

3.1. Interviews with State DOTs

In order to learn more about available practices on lane width reduction or road diet projects, we reached out to multiple DOTs in other states. We were able to set up an online interview session with the Vermont Agency of Transportation (VTrans), the Oregon Department of Transportation (ODOT), Caltrans (California), the Florida Department of Transportation (FDOT), and the Delaware Department of Transportation (DelDOT). Generally, the lane width standard in each state depends on the geographical location of roadways and traffic network needs. In addition, the walkability of cities and bike lane requirements play a significant role in the preferred minimum lane widths.

Within the interview, questions mainly focused on design criteria, design exceptions, and completed projects or future projects on urban and suburban roadways involving lane width reduction. In the case of available reduced lane width design, the project motives were analyzed, and written reports on the before-after analysis of these projects were acquired. Also, any obstacles or drawbacks experienced by reducing lane width were investigated. The summary of design practices and findings follows.

<u>3.2. Florida Department of Transportation</u>

3.2.1. Background

In 2014, the Florida Department of Transportation (FDOT) modified Urban Arterial Travel Lane Widths in low-speed areas by approving Roadway Design Bulletin 14-17. This transition is part of the low-speed urban program that FDOT has implemented and is flexible in certain contexts. The adjusted space from reducing lane width has been repurposed for “buffered bike lanes.” The objective was to dedicate exclusive lanes for bikes and increase the width of bike lanes within the network. However, this lane reduction is not applied to typical suburban areas with higher speed limits (50 mph), as it was found that this might increase crash rates, and the speed reduction is negligible. This Bulletin also established 7-foot Buffered Bicycle Lanes as the standard for marked bike lanes.

It is worth noting that FDOT used other studies and outcomes of ongoing projects as a baseline to reduce lane width for controlling speed in urban areas. However, reducing lane width solely without considering other features to lower speed and manage traffic might not be as effective. Therefore, narrowing lanes typically is combined with different traffic calming strategies to reach potential outcomes, including horizontal and/or vertical deflection, which FDOT has implemented. Horizontal deflection refers to sharp changes in horizontal alignment, as at a traffic circle or a chicane. Vertical deflection refers to sharp changes in vertical alignment, as at a speed hump or raised intersection. In addition, speed management studies by FDOT have demonstrated a small reduction in speed based on lane width, consistent with the HCM. Based on experience, reducing lane width by a foot might reduce speed by 1 or 2 mph.

FDOT recommends 10 feet as the minimum design criterion for urban conditions and 11 feet for rural areas. However, other factors, including speed limit, AADT, and truck volume, will justify wider lanes. Corridor safety is one factor that must be considered when choosing the appropriate lane width for a roadway. For instance, 10-foot lanes on 60 mph rural roads will increase crash rates. On the other hand, in urban areas, other road design variables might be more significant in affecting safety than lane width. Keeping this in mind, FDOT uses a context classification system for road design. The context classification system allows FDOT to look at the area’s needs in picking the best road design criteria.

One of the approaches FDOT takes for reducing lane width is through lane repurposing or road diets, which is changing the layout of traffic lanes for more space and reassigning the extra space to other purposes. FDOT has employed lane repurposing in various ways, including bus-only lanes, widening sidewalks, multi-use paths, on-street parking, streetcars, and bike facilities. FDOT uses the Lane Repurposing Guidebook for road diet, lane reduction, or lane elimination projects, often involving lane width reduction. Generally, in lane repurposing, a travel lane will be adjusted to accommodate other travel modes. Depending on the objective of reducing lane width and the project details, the cost might have increased, but the outcomes on roadways can justify the financial impacts.

Speed Management Pilot Projects were launched for the first time in 2019. Since speed management has been developed relatively recently and they have a five-year program, limited before-after analyses have been done. The purpose of speed management (traffic calming) is to establish a "design speed" that is appropriate for the road context. "Design speed" is a design control that sets most of the other elements in a roadway and is context based. On the other hand, "target speed" is the ideal speed that can be assigned to a particular project and will be achieved through redesigns in a corridor. These redesigns can include adding bulb-outs or adding trees to reduce speed in an area. It should be noted that "target speed" is not necessarily a lower speed; depending on the context, a higher speed might be required to match the context. Using context-based design guidelines has eased the design justification engineers need to apply to roadways. This fact helps designers look at an area's needs and pick the best design standards.

3.2.2. Roadway Design Bulletin *14-17*

FDOT approved Roadway Design Bulletin 14-17 in 2014 to modify the Urban Arterial Travel Lane Width. The Bulletin in its entirety can be found in the Appendix. Commentary included in the Bulletin contains the following statements in support of 11-foot lanes:

"Eleven-foot-wide travel lanes on urban arterials are supported by AASHTO Guidance and the Highway Safety Manual. The 2001 AASHTO Greenbook states that for interrupted-flow operating conditions, 11-foot-wide lanes are normally adequate for design speeds of 45 mph or less and even have some advantages over wider lanes. The AASHTO Guide to Bicycle Facilities also cites the Highway Safety Manual. It states that evaluation of the effects of travel lane widths of 10 to 12 feet on crashes for urban arterial roadways has found no general indication that using narrower widths within this range increases crash rates."

"The Highway Safety Manual applies crash modification factors to base conditions, such as lane width, which can be statistically correlated to crash performance. For all roadway types, except Urban and Suburban arterials, lane width is a factor in safety performance. In the case of urban arterials, it was determined, through an expert panel review process, that lane widths between 10 and 12 feet are acceptable and do not cause safety problems. There is no significant correlation between lane width and safety performance for the range of facilities studied. However, neither high truck traffic nor bus traffic was quantified in this research; therefore, it is not known if lanes as narrow as 10 feet have the same safety performance as 11- or 12-feet-wide lanes where high truck or bus traffic exists. It has been concluded, though, based on FDOT Central

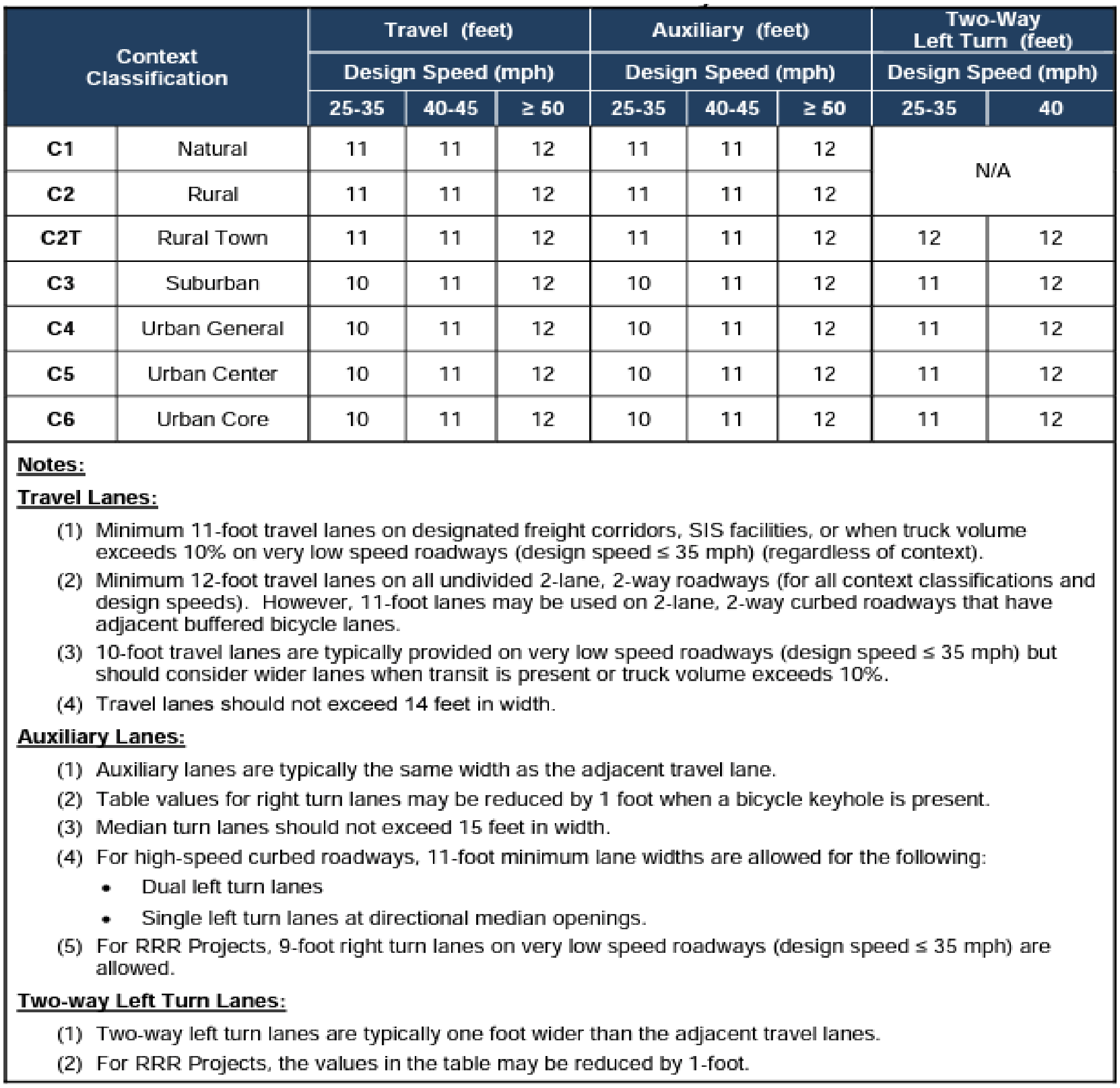
Transit Office research titled "Integrating Transit into Traditional Neighborhood Design Policies – The Influence of Lane Width on Bus Safety," that the minimum acceptable lane widths for transit operations to avoid crashes and perform turning maneuvers safely is 11 feet."

"The practice of using 11-foot-wide travel lanes on urban arterials under interrupted-flow operating conditions has become more accepted nationally. Safety research suggests that there is no safety benefit to using 12-foot-wide lanes over 11-foot-wide lanes and AASHTO publications support the use of 11-foot-wide travel lanes under these conditions."

3.2.3. FDOT Design Manual

The Florida Design Manual (FDM) sets forth geometric and other design criteria and procedures for all new construction, reconstruction, and resurfacing projects on the state and national highway systems. The criteria in this manual represent requirements for the State Highway System, which must be met for the design of FDOT projects unless approved Design Exceptions or Design Variations are obtained per the manual's procedures. Its authority is established by Sections 20.23(3)(a) and 334.048(3) of Florida Statutes. In January 2018, the FDM replaced the Plans Preparation Manual (PPM) that had been in effect since January 1998. As shown in Figure 3-1 , apart from addressing a wide range of design issues, the FDM also sets standards for lane widths on arterial and collector roads within Florida's state and national highway system. For Interstate, Freeways, and Expressways, minimum 12-foot lane widths are required.

According to the FDOT Design Manual, lane widths are selected based on design speeds. Roads and streets are classified based on context, which in turn defines target speeds. Context classification is a design control that determines key design elements for arterials and collectors. Target speed is the highest speed at which vehicles should operate on a thoroughfare in a specific context. Appropriate street design is chosen to achieve the target speed and attain the desired degree of safety, mobility, and efficiency. In a well implemented project, target speed matches design speed. Ideally, the target speed posted speed, and design speed should all be the same where speeds are 45 mph or less.



Context Classification		Travel (feet)			Auxiliary (feet)			Two-Way Left Turn (feet)	
		Design Speed (mph)			Design Speed (mph)			Design Speed (mph)	
		25-35	40-45	≥ 50	25-35	40-45	≥ 50	25-35	40
C1	Natural	11	11	12	11	11	12	N/A	
C2	Rural	11	11	12	11	11	12		
C2T	Rural Town	11	11	12	11	11	12	12	12
C3	Suburban	10	11	12	10	11	12	11	12
C4	Urban General	10	11	12	10	11	12	11	12
C5	Urban Center	10	11	12	10	11	12	11	12
C6	Urban Core	10	11	12	10	11	12	11	12

Notes:

Travel Lanes:

(1) Minimum 11-foot travel lanes on designated freight corridors, SIS facilities, or when truck volume exceeds 10% on very low speed roadways (design speed ≤ 35 mph) (regardless of context).

(2) Minimum 12-foot travel lanes on all undivided 2-lane, 2-way roadways (for all context classifications and design speeds). However, 11-foot lanes may be used on 2-lane, 2-way curbed roadways that have adjacent buffered bicycle lanes.

(3) 10-foot travel lanes are typically provided on very low speed roadways (design speed ≤ 35 mph) but should consider wider lanes when transit is present or truck volume exceeds 10%.

(4) Travel lanes should not exceed 14 feet in width.

Auxiliary Lanes:

(1) Auxiliary lanes are typically the same width as the adjacent travel lane.

(2) Table values for right turn lanes may be reduced by 1 foot when a bicycle keyhole is present.

(3) Median turn lanes should not exceed 15 feet in width.

(4) For high-speed curbed roadways, 11-foot minimum lane widths are allowed for the following:

- Dual left turn lanes
- Single left turn lanes at directional median openings.

(5) For RRR Projects, 9-foot right turn lanes on very low speed roadways (design speed ≤ 35 mph) are allowed.

Two-way Left Turn Lanes:

(1) Two-way left turn lanes are typically one foot wider than the adjacent travel lanes.

(2) For RRR Projects, the values in the table may be reduced by 1-foot.

Figure 3-1 Minimum Travel and Auxiliary Lane Widths for Arterials and Collectors

Figure 3-2 shows both context classifications and design speeds for each classification. In contrast, Figure 3-3 shows a list of strategies or street design elements that can be used to achieve those design speeds.

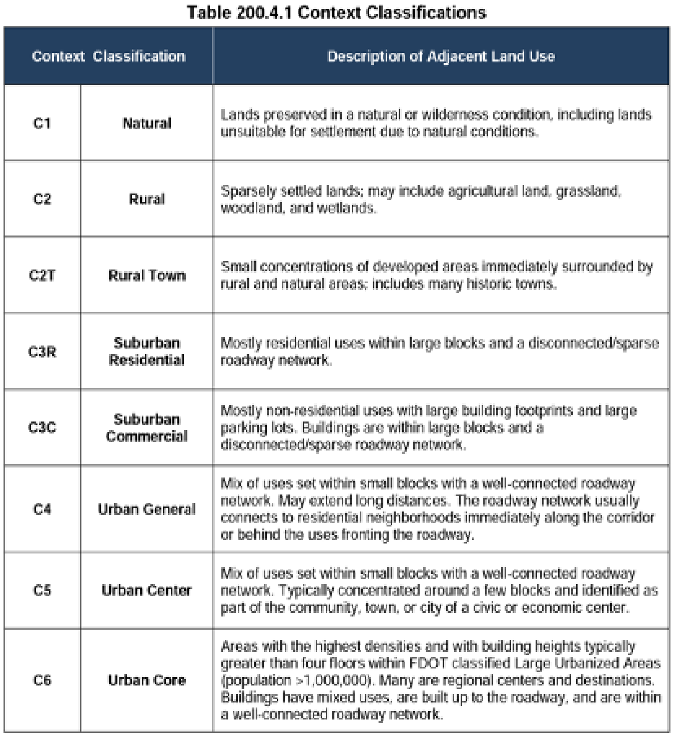


Table 200.4.1 Context Classifications

Context Classification		Description of Adjacent Land Use
C1	Natural	Lands preserved in a natural or wilderness condition, including lands unsuitable for settlement due to natural conditions.
C2	Rural	Sparsely settled lands; may include agricultural land, grassland, woodland, and wetlands.
C2T	Rural Town	Small concentrations of developed areas immediately surrounded by rural and natural areas; includes many historic towns.
C3R	Suburban Residential	Mostly residential uses within large blocks and a disconnected/sparse roadway network.
C3C	Suburban Commercial	Mostly non-residential uses with large building footprints and large parking lots. Buildings are within large blocks and a disconnected/sparse roadway network.
C4	Urban General	Mix of uses set within small blocks with a well-connected roadway network. May extend long distances. The roadway network usually connects to residential neighborhoods immediately along the corridor or behind the uses fronting the roadway.
C5	Urban Center	Mix of uses set within small blocks with a well-connected roadway network. Typically concentrated around a few blocks and identified as part of the community, town, or city of a civic or economic center.
C6	Urban Core	Areas with the highest densities and with building heights typically greater than four floors within FDOT classified Large Urbanized Areas (population >1,000,000). Many are regional centers and destinations. Buildings have mixed uses, are built up to the roadway, and are within a well-connected roadway network.

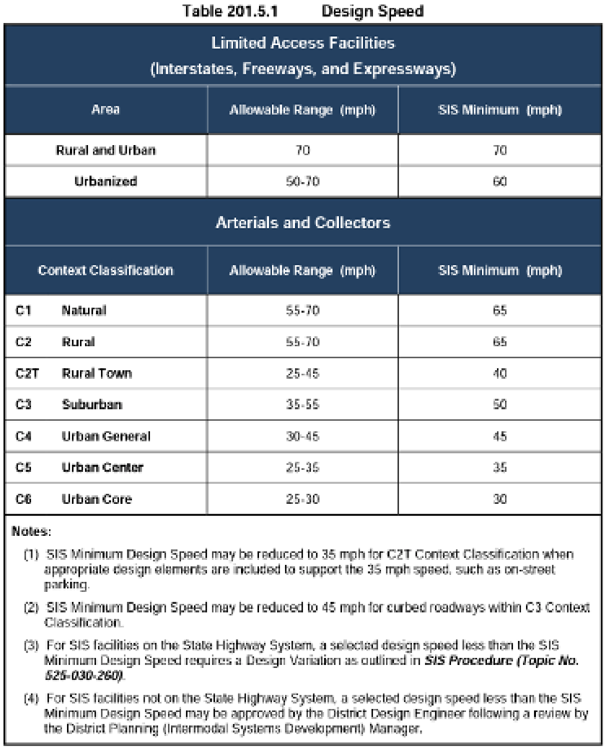


Table 201.5.1 Design Speed

Limited Access Facilities (Interstates, Freeways, and Expressways)		
Area	**Allowable Range (mph)**	**SIS Minimum (mph)**
Rural and Urban	70	70
Urbanized	50-70	60
Arterials and Collectors		
Context Classification	**Allowable Range (mph)**	**SIS Minimum (mph)**
C1 Natural	55-70	65
C2 Rural	55-70	65
C2T Rural Town	25-45	40
C3 Suburban	35-55	50
C4 Urban General	30-45	45
C5 Urban Center	25-35	35
C6 Urban Core	25-30	30

Notes:

(1) SIS Minimum Design Speed may be reduced to 35 mph for C2T Context Classification when appropriate design elements are included to support the 35 mph speed, such as on-street parking.

(2) SIS Minimum Design Speed may be reduced to 45 mph for curbed roadways within C3 Context Classification.

(3) For SIS facilities on the State Highway System, a selected design speed less than the SIS Minimum Design Speed requires a Design Variation as outlined in ***SIS Procedure (Topic No. 525-030-260)***.

(4) For SIS facilities not on the State Highway System, a selected design speed less than the SIS Minimum Design Speed may be approved by the District Design Engineer following a review by the District Planning (Intermodal Systems Development) Manager.

Figure 3-2 Context Classifications and Design Speeds

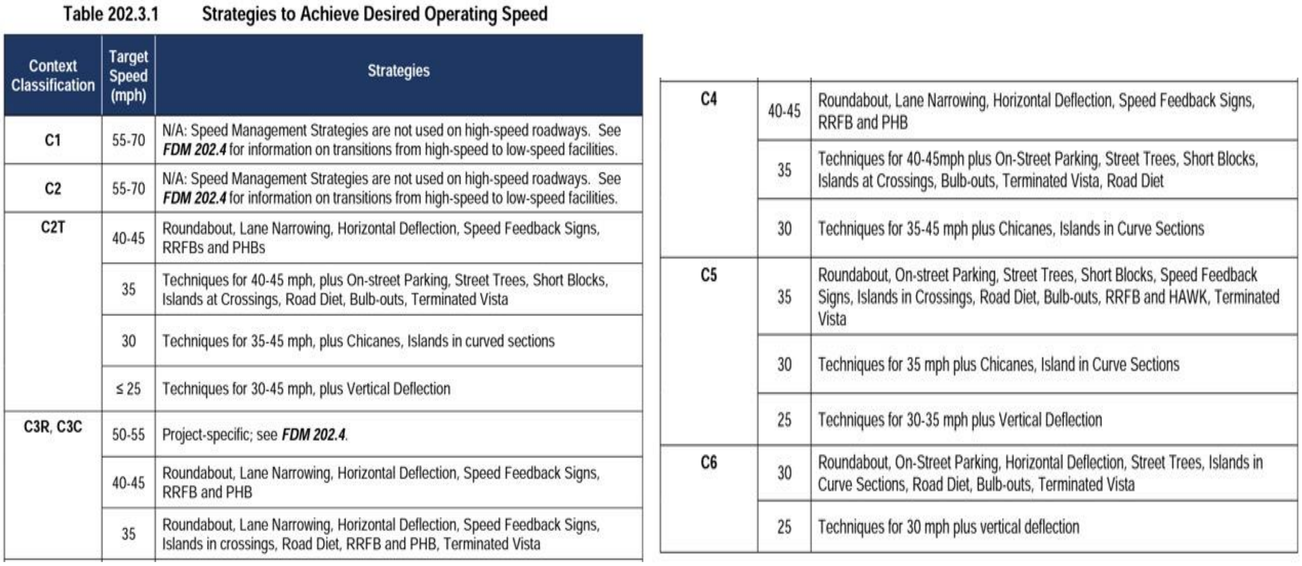


Table 202.3.1 Strategies to Achieve Desired Operating Speed

Context Classification	Target Speed (mph)	Strategies
C1	55-70	N/A: Speed Management Strategies are not used on high-speed roadways. See ***FDM 202.4*** for information on transitions from high-speed to low-speed facilities.
C2	55-70	N/A: Speed Management Strategies are not used on high-speed roadways. See ***FDM 202.4*** for information on transitions from high-speed to low-speed facilities.
C2T	40-45	Roundabout, Lane Narrowing, Horizontal Deflection, Speed Feedback Signs, RRFBs and PHBs
	35	Techniques for 40-45 mph, plus On-street Parking, Street Trees, Short Blocks, Islands at Crossings, Road Diet, Bulb-outs, Terminated Vista
	30	Techniques for 35-45 mph, plus Chicanes, Islands in curved sections
	≤ 25	Techniques for 30-45 mph, plus Vertical Deflection
C3R, C3C	50-55	Project-specific; see ***FDM 202.4***.
	40-45	Roundabout, Lane Narrowing, Horizontal Deflection, Speed Feedback Signs, RRFB and PHB
	35	Roundabout, Lane Narrowing, Horizontal Deflection, Speed Feedback Signs, Islands in crossings, Road Diet, RRFB and PHB, Terminated Vista
C4	40-45	Roundabout, Lane Narrowing, Horizontal Deflection, Speed Feedback Signs, RRFB and PHB
	35	Techniques for 40-45mph plus On-Street Parking, Street Trees, Short Blocks, Islands at Crossings, Bulb-outs, Terminated Vista, Road Diet
	30	Techniques for 35-45 mph plus Chicanes, Islands in Curve Sections
C5	35	Roundabout, On-street Parking, Street Trees, Short Blocks, Speed Feedback Signs, Islands in Crossings, Road Diet, Bulb-outs, RRFB and HAWK, Terminated Vista
	30	Techniques for 35 mph plus Chicanes, Island in Curve Sections
	25	Techniques for 30-35 mph plus Vertical Deflection
C6	30	Roundabout, On-Street Parking, Horizontal Deflection, Street Trees, Islands in Curve Sections, Road Diet, Bulb-outs, Terminated Vista
	25	Techniques for 30 mph plus vertical deflection

Figure 3-3 Strategies to achieve target speeds

The FDOT Design Manual also lists lane narrowing as a speed management strategy, while noting that "Use of narrow lanes (less than 12') alone has limited effect on operating speeds. This effect can, however, be enhanced as traffic volumes increase. The visible narrowing of travel lanes may be used as a transition device to clearly indicate a change in context. For instance, narrowing two 12-foot lanes to two 11-foot or 10-foot lanes by shifting the lane lines slightly and introducing a hatch in the newly created edge space has been shown to alert drivers of a change in condition or context. To maximize effectiveness, lane narrowing should be used in conjunction with other low-speed strategies (e.g., the introduction of parking, the creation of a median, and the beginning of a chicane)."

3.2.4. The Manual of Uniform Minimum Standards for Design, Construction and Maintenance (Florida Greenbook)

This manual is intended for all projects, not on the state and national highway systems. Its authority is established by Chapters 20.23(3)(a), 334.044(10)(a), and 336.045, Florida Statutes, and Rule 14-15.002, Florida Administrative Code. The manual provides criteria for public streets, roads, highways, bridges, sidewalks, curbs and curb ramps, crosswalks, bicycle facilities, underpasses, and overpasses used by the public for vehicular and pedestrian travel. Figure 3-4 shows the minimum lane widths suggested by the manual.

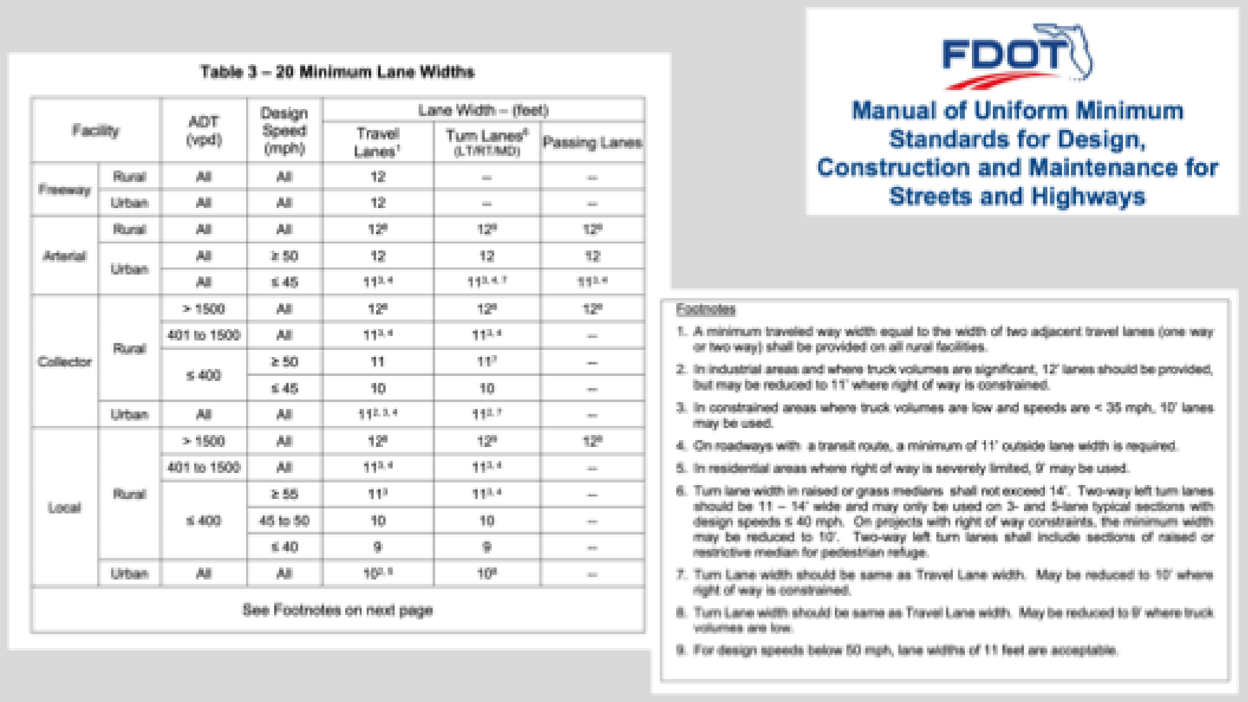


Table 3 – 20 Minimum Lane Widths

Facility		ADT (vpd)	Design Speed (mph)	Lane Width – (feet)		
				Travel Lanes[1]	Turn Lanes[6] (LT/RT/MD)	Passing Lanes
Freeway	Rural	All	All	12	–	–
	Urban	All	All	12	–	–
Arterial	Rural	All	All	12^9	12^9	12^9
	Urban	All	≥ 50	12	12	12
		All	≤ 45	$11^{3,4}$	$11^{3,4,7}$	$11^{3,4}$
Collector	Rural	> 1500	All	12^9	12^9	12^9
		401 to 1500	All	$11^{3,4}$	$11^{3,4}$	–
		≤ 400	≥ 50	11	11^7	–
			≤ 45	10	10	–
	Urban	All	All	$11^{2,3,4}$	$11^{2,7}$	–
Local	Rural	> 1500	All	12^9	12^9	12^9
		401 to 1500	All	$11^{3,4}$	$11^{3,4}$	–
		≤ 400	≥ 55	11^3	$11^{3,4}$	–
			45 to 50	10	10	–
			≤ 40	9	9	–
	Urban	All	All	$10^{2,5}$	10^8	–

See Footnotes on next page

FDOT

Manual of Uniform Minimum Standards for Design, Construction and Maintenance for Streets and Highways

Footnotes

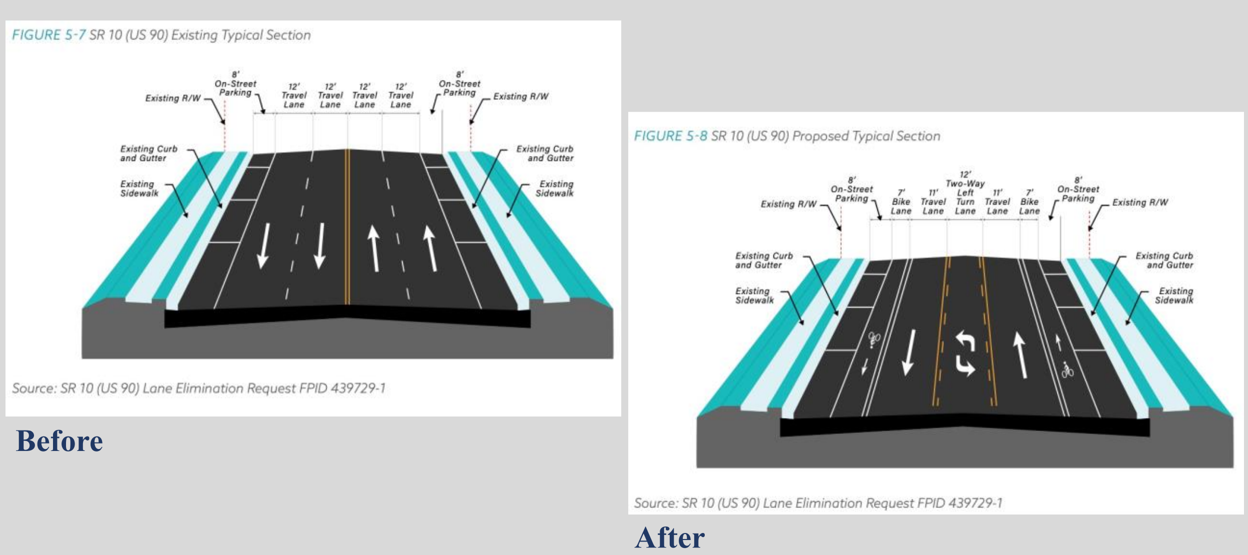
1. A minimum traveled way width equal to the width of two adjacent travel lanes (one way or two way) shall be provided on all rural facilities.
2. In industrial areas and where truck volumes are significant, 12' lanes should be provided, but may be reduced to 11' where right of way is constrained.
3. In constrained areas where truck volumes are low and speeds are < 35 mph, 10' lanes may be used.
4. On roadways with a transit route, a minimum of 11' outside lane width is required.
5. In residential areas where right of way is severely limited, 9' may be used.
6. Turn lane width in raised or grass medians shall not exceed 14'. Two-way left turn lanes should be 11 – 14' wide and may only be used on 3- and 5-lane typical sections with design speeds ≤ 40 mph. On projects with right of way constraints, the minimum width may be reduced to 10'. Two-way left turn lanes shall include sections of raised or restrictive median for pedestrian refuge.
7. Turn Lane width should be same as Travel Lane width. May be reduced to 10' where right of way is constrained.
8. Turn Lane width should be same as Travel Lane width. May be reduced to 9' where truck volumes are low.
9. For design speeds below 50 mph, lane widths of 11 feet are acceptable.

Figure 3-4 Minimum Lane Widths (Florida Greenbook)

3.2.5. Lane Repurposing Guidebook

Lane repurposing projects involve changes to the roadway cross section and restriping existing travel lanes for either a roadway segment or an entire corridor. The changes may include design modifications such as reduced lane widths, median changes, access management modifications, bicycle lanes, new or wider sidewalks, shared-use paths, on-street parking or transit-only lanes, or loading/transportation network company (TNC) zones.

The guidebook serves as a resource for local, regional, and statewide transportation agency planners and engineers to analyze potential lane repurposing projects and includes the potential factors to be considered prior to design and implementation. A lane repurposing project done by FDOT is shown in Figure 3-5.



Before

After

Figure 3-5 S.R. 10 (U.S. 90) Monticello, Jefferson County

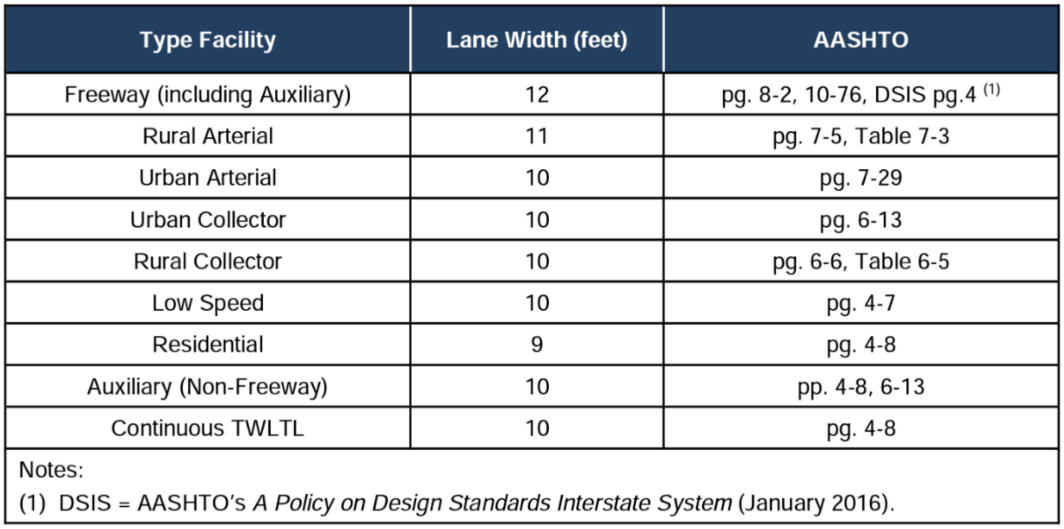
3.2.6 Design Exceptions

Design exceptions and variations are considered when proposed values are below minimum standards. In case the existing or proposed design element is not compatible with both AASHTO and department governing criteria, design exceptions are required, and design variation is required in case of incompatibility with the department’s standards alone. Before Phase I design submittal, identification is necessary to initiate a design exception or variation. Design exception or variation documents require approval prior to Phase II of design submittal.

FDM recommends using the following mitigation strategies for lane width exceptions and variations:

- Optimal combination of shoulder and lane width for optimal safety,
- In-advance signing of road lane width changes,
- Increased safety by the employment of sensory tools to mark lanes,
- Creating safe shoulder and edge for drivers in case of leaving the lane,
- Reduce the severity of crashes with a safe design on road shoulders.

If the new design value has safety aspects, FDOT requires a benefit and cost analysis. This analysis is based on the reduced number of crashes and aggregated costs during the project's life. The state roadway design engineer will review a request for a design exception. Depending on the project's scope, the chief engineer, state structure engineer, planning office, and FHWA may also be involved. For design variations, district level approval is required. FDOT only requires state roadway design engineer approval for lane width design exceptions.



Type Facility	Lane Width (feet)	AASHTO
Freeway (including Auxiliary)	12	pg. 8-2, 10-76, DSIS pg.4 (1)
Rural Arterial	11	pg. 7-5, Table 7-3
Urban Arterial	10	pg. 7-29
Urban Collector	10	pg. 6-13
Rural Collector	10	pg. 6-6, Table 6-5
Low Speed	10	pg. 4-7
Residential	9	pg. 4-8
Auxiliary (Non-Freeway)	10	pp. 4-8, 6-13
Continuous TWLTL	10	pg. 4-8

Notes:
(1) DSIS = AASHTO's *A Policy on Design Standards Interstate System* (January 2016).

Figure 3-6 AASHTO Minimum Lane Width by Road Classification (FDM)

3.2.7 Speed Management (Traffic Calming)

FDM has developed speed management practices for arterials and collectors in low-speed areas. The objective of speed management is to reduce the operating speed to a target speed safe for context classification. Lane repurposing is used as one of the tools to facilitate speed management by removing travel lanes and creating extra space. FDM suggests that using cognitive senses in drivers by creating roadways that alert users both on-road and roadside will help manage speed. Besides, changes in geometric design, including horizontal and vertical deflection, attract drivers' attention and, correspondingly, can be employed as speed management strategies.

Speed management strategies are applied to reach a 'target speed.' Target speed is defined as the highest speed in a corridor that will increase mobility and safety for all modes of transportation. It is recommended to utilize available sources optimally for speed management purposes. Yet, multiple strategies are suggested by FDM to manage speed that can be applied depending on road classification, user types and needs, access management, and desired speed. These strategies are listed as follows:

- Roundabouts,
- On-Street Parking[1]
- Chicanes
- Lane Narrowing
- Horizontal and Vertical[2] Deflections
- Street Trees
- Short Blocks
- Speed Feedback Signs
- Road Posted Speed Marking
- Islands
- Bulb-Outs
- Hybrid Beacons
- Terminated Vistas

Among speed management strategies, narrowing lanes on its own might not be beneficial in reducing speed. However, higher volume roadways show a more significant difference. Combined with other speed management strategies, lane narrowing has been shown to be more effective. Speed management strategies also may be applied in transition zones where roadway classifications change. Application of lane narrowing along with other methods is recommended to reduce speed in perception-reaction areas.

For instance, on S.R. 582, reducing lane width to 11 feet with changing posted speed limit from 50 to 45 mph successfully reduced the average speed by 3 mph. The same trend was observed

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[1] Travel lanes must be 11 feet or less.

[2] Mostly recommended for target speeds of 30 mph or less.

on Busch Boulevard with the application of Speed Feedback Signs (SFS), median islands, and reducing lane width from 12 to 11 feet. Speed reduction is most significant downstream of the boulevard (4 mph speed reduction) and SFS signs with narrower lanes, indicating the efficiency of multiple practices in traffic speed management.

3.3. ***Vermont Agency of Transportation***

3.3.1. Background

Vermont Agency of Transportation (VTrans) aims at providing a safe, reliable, and multimodal transportation system that promotes economic growth and is affordable and socially equitable for all. With this vision, VTrans adopted Vermont State Design Standards 25 years ago, a unique and visionary step for a transportation agency fighting the odds at the state legislature in establishing flexibility and contextuality in the roadway design process. Going beyond the 10-12-foot lane widths set by AASHTO in the "Green Book," VTrans set the minimum lane width as low as 9 feet which triggers our interest in this case study. While interviewing officials from VTrans, we came to know this minimum standard has not been applied to new construction and reconstruction on state routes even though the law permits it. According to the officials, the winter climate of Vermont played a big part here. Whereas the primary reason that initiated the formulation of these standards was to ensure a complete street, especially to accommodate the bicyclist, this added flexibility was more helpful for 3R (resurfacing, restoration, and rehabilitation) projects, allowing better utilization of the space to accommodate bicyclists and traffic without any large-scale investment in lane widening.

3.3.2. Vermont State Design Standards

In 1997, VTrans adopted Vermont State Design Standards to allow flexibility in the technical guidelines for designing roadway projects that fit into the social context of the state, minimize the environmental impact, and maximize the public benefits. The standards laid out in this document guide the physical design parameters of roadways and bridges. In some cases, they augment the standards previously used by VTrans, and the guidelines of AASHTO. Speed, traffic volume, and functional classification of roadways are the determining factors for lane width standards.

Index 3.5 and Index 4.5 of the Design Standards establish lane widths for urban and village principal arterials and minor arterials, respectively. Because of the large difference in urban and village settings, the manual provides no table of values but provides the following guidelines:

- Lane widths on urban and village principal arterials may vary from 10 to 12 feet, and there should be appropriate offsets to curb.
- For highly restricted areas having little or no truck traffic, 10-foot widths are appropriate.
- The 11-foot lanes are primarily used for urban and village principal arterial street designs.
- The 12-foot widths are applicable for all higher-speed, free-flowing principal arterials.

Along with the above-mentioned guidelines, the document prescribes special cases for adopting narrower lane widths. According to the document, "*Under interrupted-flow conditions at low speeds (up to 45 mph), the narrower lane widths are normally adequate and have some advantages. Reduced lane widths allow greater numbers of lanes in the restricted right-of-way and facilitate pedestrian crossings because of reduced distance. They are also more economical to construct. 11-foot lane width is adequate for through lanes, continuous two-way left-turn lanes, and a lane adjacent to a painted median. A 10- foot left-turn lane, or a combination lane used for parking, with traffic during peak hours, is also acceptable.*"

Index 3.6 and 4.6 of Vermont State Design Standards provides standards in tabular format for lane width of rural principal arterials and rural minor arterials, respectively. They vary from 11-12 feet, depending on design speed and ADT, as shown in Figures 3-7 and 3-8.

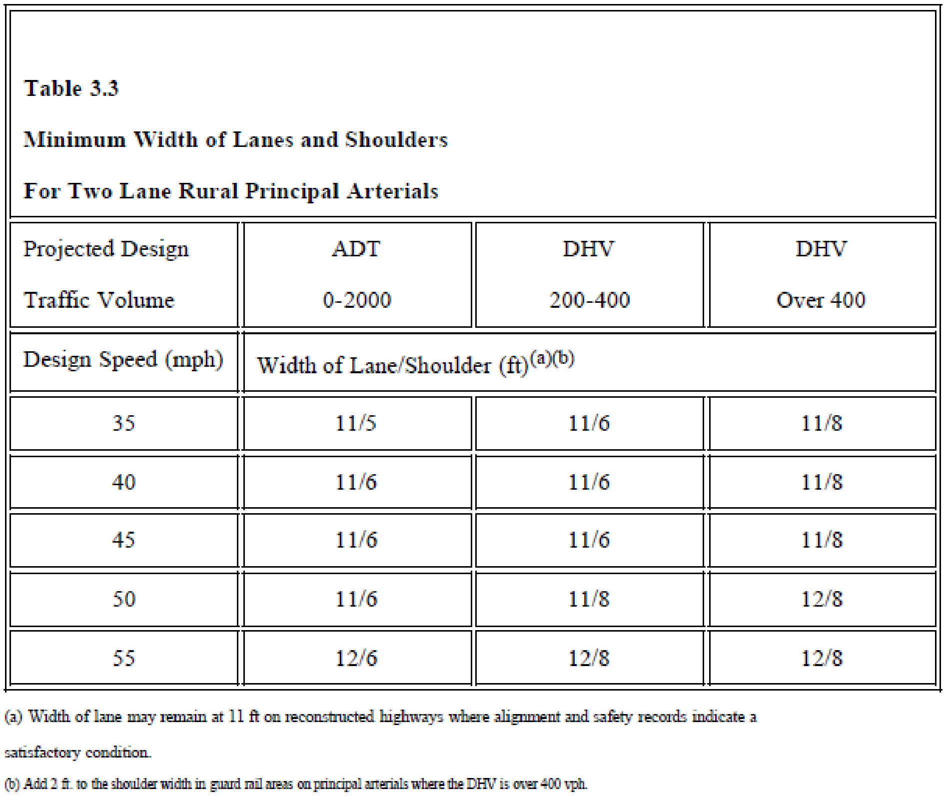


Table 3.3

Minimum Width of Lanes and Shoulders

For Two Lane Rural Principal Arterials

Projected Design Traffic Volume	ADT 0-2000	DHV 200-400	DHV Over 400
Design Speed (mph)	Width of Lane/Shoulder (ft)(a)(b)		
35	11/5	11/6	11/8
40	11/6	11/6	11/8
45	11/6	11/6	11/8
50	11/6	11/8	12/8
55	12/6	12/8	12/8

(a) Width of lane may remain at 11 ft on reconstructed highways where alignment and safety records indicate a satisfactory condition.

(b) Add 2 ft. to the shoulder width in guard rail areas on principal arterials where the DHV is over 400 vph.

Figure 3-7 Minimum Lane Width of Two-Lane Rural Principal Arterials

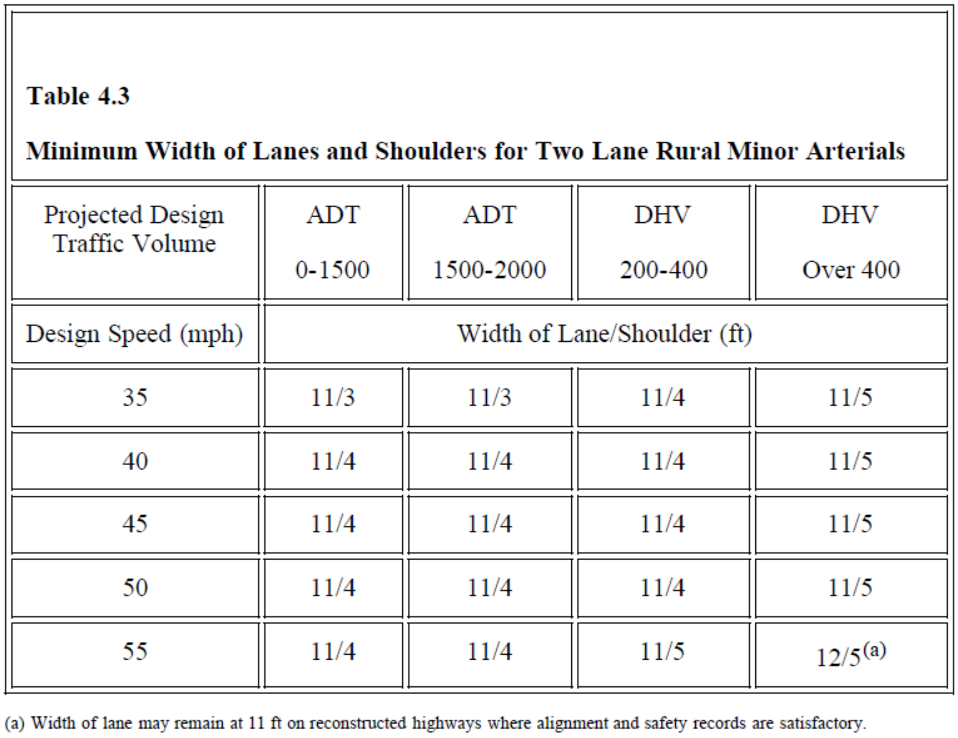


Table 4.3

Minimum Width of Lanes and Shoulders for Two Lane Rural Minor Arterials

Projected Design Traffic Volume	ADT 0-1500	ADT 1500-2000	DHV 200-400	DHV Over 400
Design Speed (mph)	Width of Lane/Shoulder (ft)			
35	11/3	11/3	11/4	11/5
40	11/4	11/4	11/4	11/5
45	11/4	11/4	11/4	11/5
50	11/4	11/4	11/4	11/5
55	11/4	11/4	11/5	12/5(a)

(a) Width of lane may remain at 11 ft on reconstructed highways where alignment and safety records are satisfactory.

Figure 3-8 Minimum Lane Width of Two-Lane Minor Arterials

Lane width for urban and village collectors is discussed in the next chapter, and it can vary from 9 to 11 feet according to Index 5.5 of Vermont State Design Standards. According to the manual, "*The 9-foot widths are appropriate in highly restricted areas having little or no truck traffic. The 11-foot lane widths are generally used on all higher speed, free-flowing Collectors.*" Moreover, Figure 3-9 provides guidance for lane widths of rural collectors.

In the following chapter, the lane width of local streets is mentioned. According to Index 6.4 of this chapter, urban and village local streets can vary from 7 to 11 feet. 7 to 8 feet road widths are more appropriate for residential areas with low traffic volumes. However, the manual provides Figure 3-10 for new construction, lane, and shoulder width in rural local roads.

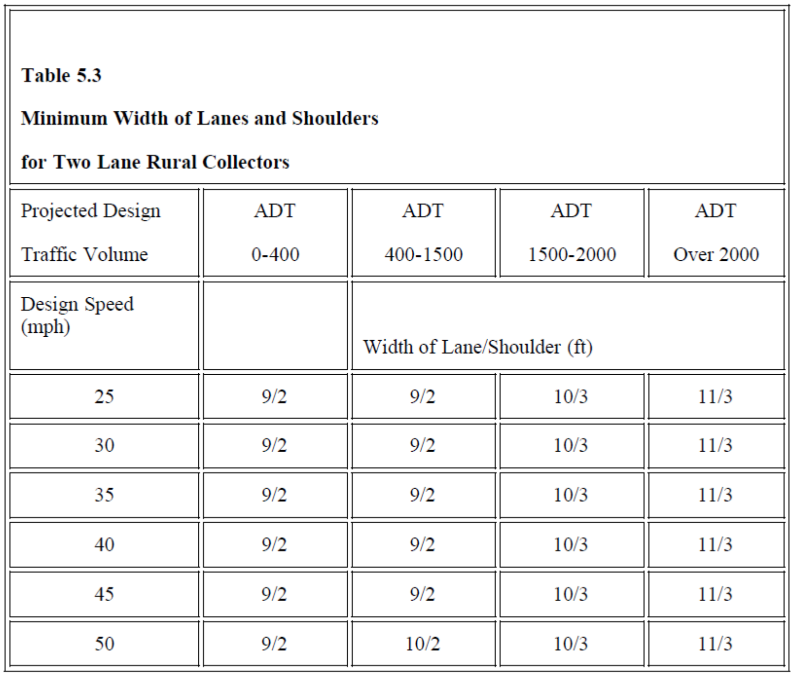


Table 5.3

Minimum Width of Lanes and Shoulders

for Two Lane Rural Collectors

Projected Design Traffic Volume	ADT 0-400	ADT 400-1500	ADT 1500-2000	ADT Over 2000
Design Speed (mph)		Width of Lane/Shoulder (ft)		
25	9/2	9/2	10/3	11/3
30	9/2	9/2	10/3	11/3
35	9/2	9/2	10/3	11/3
40	9/2	9/2	10/3	11/3
45	9/2	9/2	10/3	11/3
50	9/2	10/2	10/3	11/3

Figure 3-9 Minimum Lane Width of Two-Lane Rural Collectors

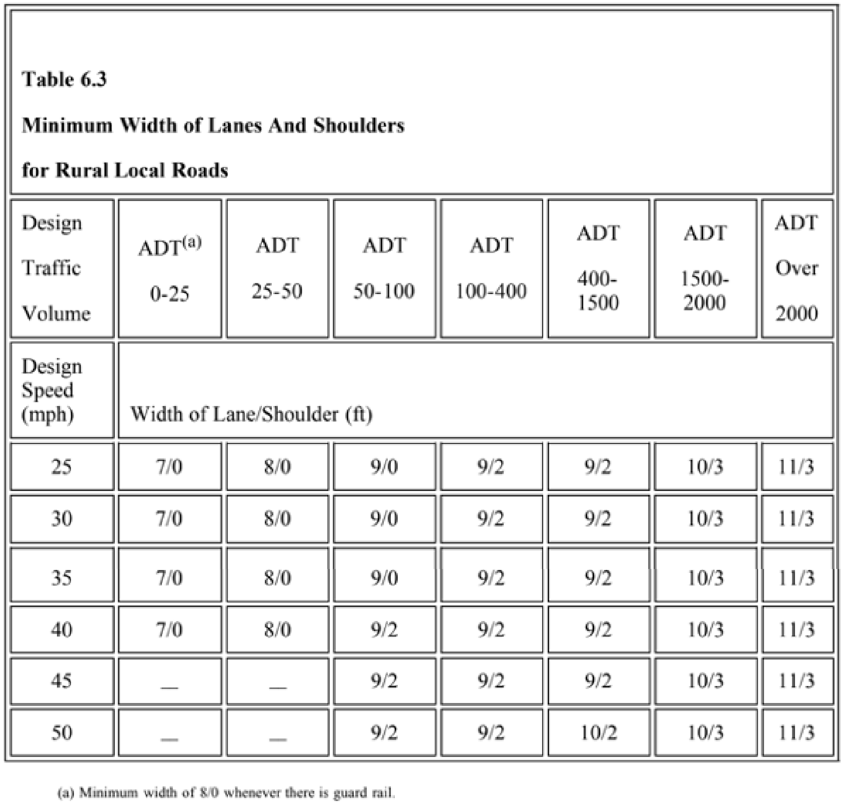


Table 6.3

Minimum Width of Lanes And Shoulders for Rural Local Roads

Design Traffic Volume	ADT[(a)] 0-25	ADT 25-50	ADT 50-100	ADT 100-400	ADT 400-1500	ADT 1500-2000	ADT Over 2000
Design Speed (mph)	Width of Lane/Shoulder (ft)						
25	7/0	8/0	9/0	9/2	9/2	10/3	11/3
30	7/0	8/0	9/0	9/2	9/2	10/3	11/3
35	7/0	8/0	9/0	9/2	9/2	10/3	11/3
40	7/0	8/0	9/2	9/2	9/2	10/3	11/3
45	—	—	9/2	9/2	9/2	10/3	11/3
50	—	—	9/2	9/2	10/2	10/3	11/3

(a) Minimum width of 8/0 whenever there is guard rail.

Figure 3-10 Minimum Lane Width of Rural Local Roads

3.3.3. Road Design Manual (VAOT)

The Road Design Manual is documentation of guiding principles that are adhered to by VTrans while designing a roadway. While designing a roadway, VTrans uses Vermont State Design Standards unless a design exception is approved. It also uses VAOT Standard Specifications for Construction, Supplemental Specifications, General Special Provisions, Special Provisions, standard drawings and details, and lastly, it considers *A Policy on Geometric Design of Highways and Streets,* the AASHTO “Green Book.”

In addition, it is stated that “*The Vermont State Standards provide guidance for lane and shoulder width considerations when bicycles and pedestrians must share the roadway. Refer to the AASHTO Guide for the Development of Bicycle Facilities for additional design criteria.*”

However, lane widths for 3R (resurfacing, restoration, and rehabilitation) projects on rural roadways should be a minimum of 3.6 meters for arterial highways and 3.3 meters for all other state highways. Moreover, the manual states that “*The total width of a two-lane rural roadway,* *including shoulders and travel lanes, will be not less than the width as originally constructed, will be within 3 meters of the new construction standard per the Vermont State Standards and the AASHTO Green Book.*"

3.3.4. Complete Streets. A Guidebook for Vermont Communities

This guidebook was developed by the Vermont Department of Health under its Fit and Healthy Vermonter Program and implemented under Act 34 of 2011, requiring municipals to adopt a transportation policy that considers all users, including pedestrians, bicyclists, and transit riders. The guidebook suggests resurfacing (3R) as an excellent opportunity to provide complete streets to the community. Especially when 12-feet lane width was considered a "basic" standard, this guidebook states that "*VTrans has established a range of acceptable lane widths for the local, collector, and minor arterial streets. They allow for 10- to 11-foot lanes under pretty much all urban, downtown, or village conditions (i.e., C3-C6) and will accept 9-foot lanes on local streets. Rural roads typically require 11-foot lanes*."

It also mentions "right-sizing" major roadways to make room for active modes of transportation in road diet projects. VTrans and other transportation agencies in Vermont were employing the concept of the complete street well before Act 34 was passed in 2011.

3.3.5. Traffic Calming Measures

Traditional traffic calming measures (both horizontal & vertical) often are avoided due to wintertime maintenance activities in states with heavy snowfall like Vermont. To overcome this limitation, a psycho-perceptive method was experimented with by VTrans and Windham Regional Commission, known as "dynamic striping." It was intended to reduce driving speed with visual cues, using a series of transverse markings with increased widths and decreased distance between them. It is expected to reduce vehicular speeds at the edge of each village (Newfane, Townshend, Jamaica, and Bondville, located along VT Route 30) by drawing drivers' awareness and creating an illusion of increasing speed along with reduced lane width.

After installing the striping layout, traffic speeds were monitored periodically, and necessary data were collected. Analyzing the speed, the dynamic stripes were proven marginally effective in reducing vehicular speeds. Immediately after one week of installation, an average reduction in speed of .01 mph was observed, which improved over time with an average decrease in speed of 1.0 mph after four months. Moreover, evidence suggests that striping has a larger effect on drivers that are exposed daily on this route. However, according to the report, "*Overall, the results from this study are not compelling given the large amounts of variability resulting in standard deviations ranging from 0.5 mph to 3.9 mph. While the effectiveness of the stripes may seem somewhat insignificant, this study proves that it increases over time due to driver awareness and recognition. Feedback from local residents indicates that the dynamic stripes act more as a signal that the village is coming up, and due to the consistency of the stripes in the four villages, the stripes are viewed as a "village approaching" indicator.*"

*3.4. **Oregon Department of Transportation***

3.4.1. Background

The 1999 Oregon Highway Plan created new Highway Segment Designations that were authorized by the Oregon Transportation Commission. The highway segment designations of Special Transportation Areas (STAs), Urban Business Areas (UBAs), and Commercial Centers were used as tools to implement more compact community development patterns. The preferred lane width was reduced to 11 feet in STAs. However, for the rest of the highway system, the standard lane width was maintained at 12 feet. Reductions were allowed with design exceptions. Over the years, ODOT has used design exceptions as a means of providing flexibility on projects as needed but has not wholesale reduced lane width standards from 12 feet except for STAs.

In 2001, the Oregon Legislature formalized the Oregon Freight Advisory Committee, or OFAC, through the passage of House Bill 3364 (now ORS 366.212). This legislation calls for the Oregon Department of Transportation Director to "appoint members of a Freight Advisory Committee to advise the Director and Oregon Transportation Commission on issues, policies, and programs that impact multimodal freight mobility in Oregon." Subsequently, ORS 366.215 ("Creation of state highways; reduction in vehicle-carrying capacity") was adopted. It states that the "vehicle-carrying capacity" of an identified freight route (aka Reduction Review Route) may not be permanently reduced unless safety or access considerations require the reduction, or a local government requests an exemption, and the Commission determines it is in the best interest of the state, and freight movement is not unreasonably impeded. In practice, it limits ODOT's ability to make changes to a roadway cross section that would impact freight and commerce. The term "vehicle-carrying capacity" was insufficiently explained and meant that even a traffic signal could have not been put in place without prior discussions with the freight industry.

In 2013, an OAR (Oregon Advisory Role) was created to guide the implementation of ORS 366.215. For the purposes of implementing ORS 366.215 and following the OAR guidelines, ODOT established a system of Reduction Review Routes which includes all parts of the state highway system that must be traveled to complete the prescribed route and/or connect with other state highways. Another direct outcome of ORS 366.215 was the creation of the Mobility Advisory Committee (MAC), which consists of representatives of widely defined freight interest groups, including the trucking industry, mobile home manufacturers, oversize load freight, general contractors, and paving contractors. Any proposed changes to street/road cross sections must be presented to the Mobility Advisory Committee (MAC) group. Even though the group does not hold veto power, ODOT seeks to make accommodations for vehicles that are permitted to use those routes - 18-foot-wide, 245-feet long, up to million-pound vehicles. These restrictions impact and sometimes impede what ODOT can do in relation to lane widths:

"*When we looked at the Blueprint for Urban Design, we wholeheartedly wanted to reduce our lane widths as much as possible, but we don't always have the ability to do that. This depends on what we can do to accommodate freight. Even when putting in a six-inch-high raised curb median, we have to discuss it with our freight partners regarding how that's going to affect their ability to get freight through from a commerce standpoint and economic standpoint*." (Rich Crossler-Laird, Senior Urban Design Engineer at Oregon Department of Transportation)

3.4.2 Guiding Documents

ODOT has created two documents to provide roadway related design guidance: the Highway Design Manual (HTM) and the Blueprint for Urban Design, which in turn consists of two volumes where Volume One lays out the focus and the performance-based practice design policy and Volume Two provides background information and key documentation (Figure 3-11).

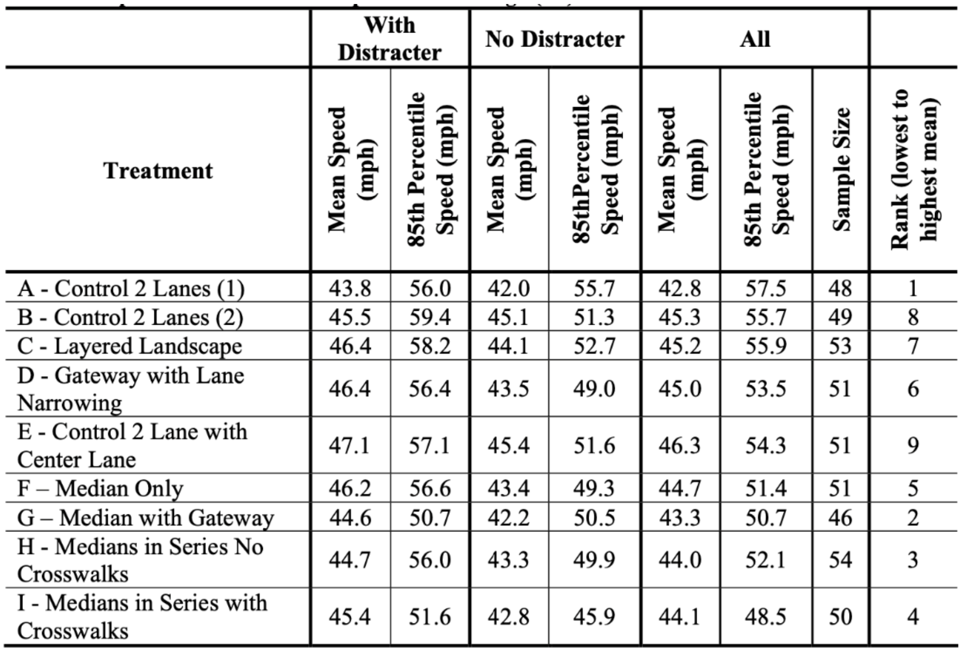
Oregon DOT has not conducted any studies (e.g., before-after studies) regarding lane width reduction, but it has used scholarly guidance when establishing its criteria for the Blueprint for

Urban Design. Douglas Harwood (Midwest Research Institute or MRIGlobal) was one of the scholars whose work influenced ODOT’s approach to lane width standards.

“His research shows that reducing lanes does not increase crash frequency, doesn't affect throughput or capacities necessarily, but once you go below 11 feet, then you potentially have increased sideswipe crashes and some potential slowing of vehicles. It also showed that just reducing lane width by itself doesn't necessarily slow vehicles down. There might be an initial effect, but once people are used to it, the speed goes back up. A combination of things along with the lane narrowing produces better lasting effects - introducing on-street parking, adding some verticality to the cross-section, etc. But just any one of those things by itself doesn't get a noticeable reduction of speed. It's everything together - the whole cross-section.” (Rich Crossler-Laird, Senior Urban Design Engineer at Oregon Department of Transportation)

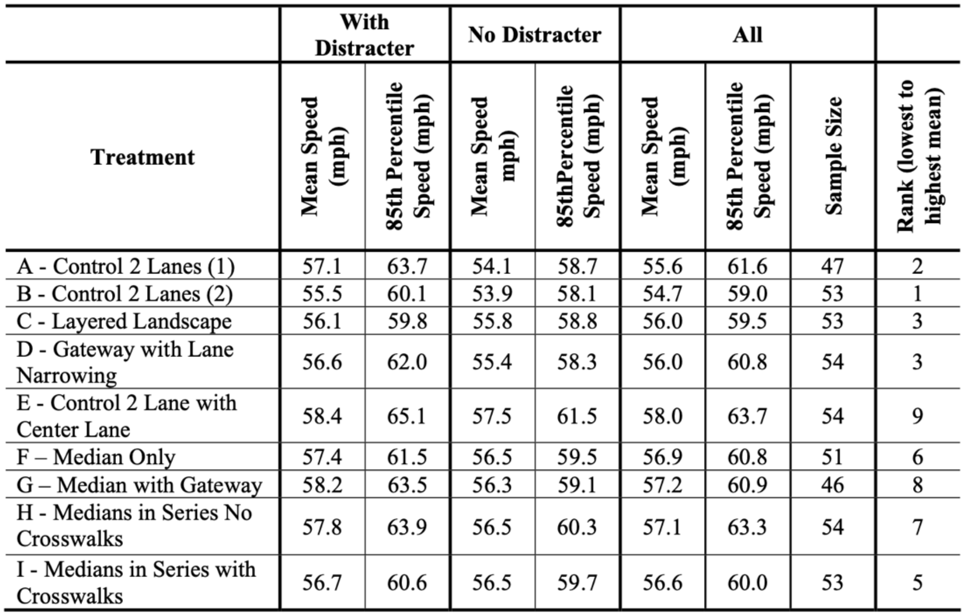
In 2008, ODOT also commissioned a study by Karen Dixon (Assistant Professor at Oregon State University) to determine the best roadway design treatments for transitioning from rural areas to urban areas on state highways (Dixon, 2008). The main objective of the study was to identify ways to calm operating speeds as vehicles transition into developed suburban/urban areas from rural roads. The study evaluated whether either physically or perceptually narrowing the road at these transition locations leads to speed reduction.

The specific transition treatments included (1) layered landscape, (2) gateway with lane narrowing, (3) median treatment only, (4) median with gateway treatment, (5) medians in series with no pedestrian crosswalks, and (6) medians in series with pedestrian crosswalks. The study found that the layered landscape treatment and the gateway with lane narrowing treatment did not result in statistically significant speed reductions. The scenarios with the most effective speed reduction results (although still minimal) included the median treatments (particularly the medians in a series or the treatment combined with a gateway). Results are shown in Figures 3-11 and 3-12.



Treatment	With Distracter		No Distracter		All			
	Mean Speed (mph)	85th Percentile Speed (mph)	Mean Speed (mph)	85thPercentile Speed (mph)	Mean Speed (mph)	85th Percentile Speed (mph)	Sample Size	Rank (lowest to highest mean)
A - Control 2 Lanes (1)	43.8	56.0	42.0	55.7	42.8	57.5	48	1
B - Control 2 Lanes (2)	45.5	59.4	45.1	51.3	45.3	55.7	49	8
C - Layered Landscape	46.4	58.2	44.1	52.7	45.2	55.9	53	7
D - Gateway with Lane Narrowing	46.4	56.4	43.5	49.0	45.0	53.5	51	6
E - Control 2 Lane with Center Lane	47.1	57.1	45.4	51.6	46.3	54.3	51	9
F – Median Only	46.2	56.6	43.4	49.3	44.7	51.4	51	5
G – Median with Gateway	44.6	50.7	42.2	50.5	43.3	50.7	46	2
H - Medians in Series No Crosswalks	44.7	56.0	43.3	49.9	44.0	52.1	54	3
I - Medians in Series with Crosswalks	45.4	51.6	42.8	45.9	44.1	48.5	50	4

Figure 3-11 Speed Characteristics at Speed Limit 35 Sign



Treatment	With Distracter		No Distracter		All			
	Mean Speed (mph)	85th Percentile Speed (mph)	Mean Speed mph)	85thPercentile Speed (mph)	Mean Speed (mph)	85th Percentile Speed (mph)	Sample Size	Rank (lowest to highest mean)
A - Control 2 Lanes (1)	57.1	63.7	54.1	58.7	55.6	61.6	47	2
B - Control 2 Lanes (2)	55.5	60.1	53.9	58.1	54.7	59.0	53	1
C - Layered Landscape	56.1	59.8	55.8	58.8	56.0	59.5	53	3
D - Gateway with Lane Narrowing	56.6	62.0	55.4	58.3	56.0	60.8	54	3
E - Control 2 Lane with Center Lane	58.4	65.1	57.5	61.5	58.0	63.7	54	9
F – Median Only	57.4	61.5	56.5	59.5	56.9	60.8	51	6
G – Median with Gateway	58.2	63.5	56.3	59.1	57.2	60.9	46	8
H - Medians in Series No Crosswalks	57.8	63.9	56.5	60.3	57.1	63.3	54	7
I - Medians in Series with Crosswalks	56.7	60.6	56.5	59.7	56.6	60.0	53	5

Figure 3-12 Speed Characteristics at Speed Limit 55 Sign

Figure 3-13 ODOT Road Design Guiding Documents

3.4.3 Highway Design Manual 2023

The ODOT Highway Design Manual (HDM) is the primary document for roadway design on the state highway system and the version currently in use was last updated in 2012. The Highway Design Manual 2012 focuses on presenting the appropriate design standards relevant to various project types, which are defined to assist the designer in applying the proper standards to the project. In short, it provides roadway-related design guidance. The 2023 Highway Design Manual went into effect in January of 2023 and includes the Blueprint for Urban Design which previously had functioned as an independent document.

The expanded 2023 manual provides uniform standards and procedures for ODOT. It is intended to provide the standards and guidance for the design of all projects that are located on State highways: new construction and major reconstruction (4R), resurfacing, restoration, and rehabilitation (3R), and resurfacing (1R) projects. The HDM is used in conjunction with Technical Bulletins, Technical Directives, Technical Advisories, and relevant guidance documents. The flexibility contained in the 2023 Highway Design Manual supports the use of Performance-Based Practical Design concepts and Context Sensitive Design practices (earlier described in the Blueprint for Urban Design). An updated 2024 HDM will become effective on March 1, 2024.

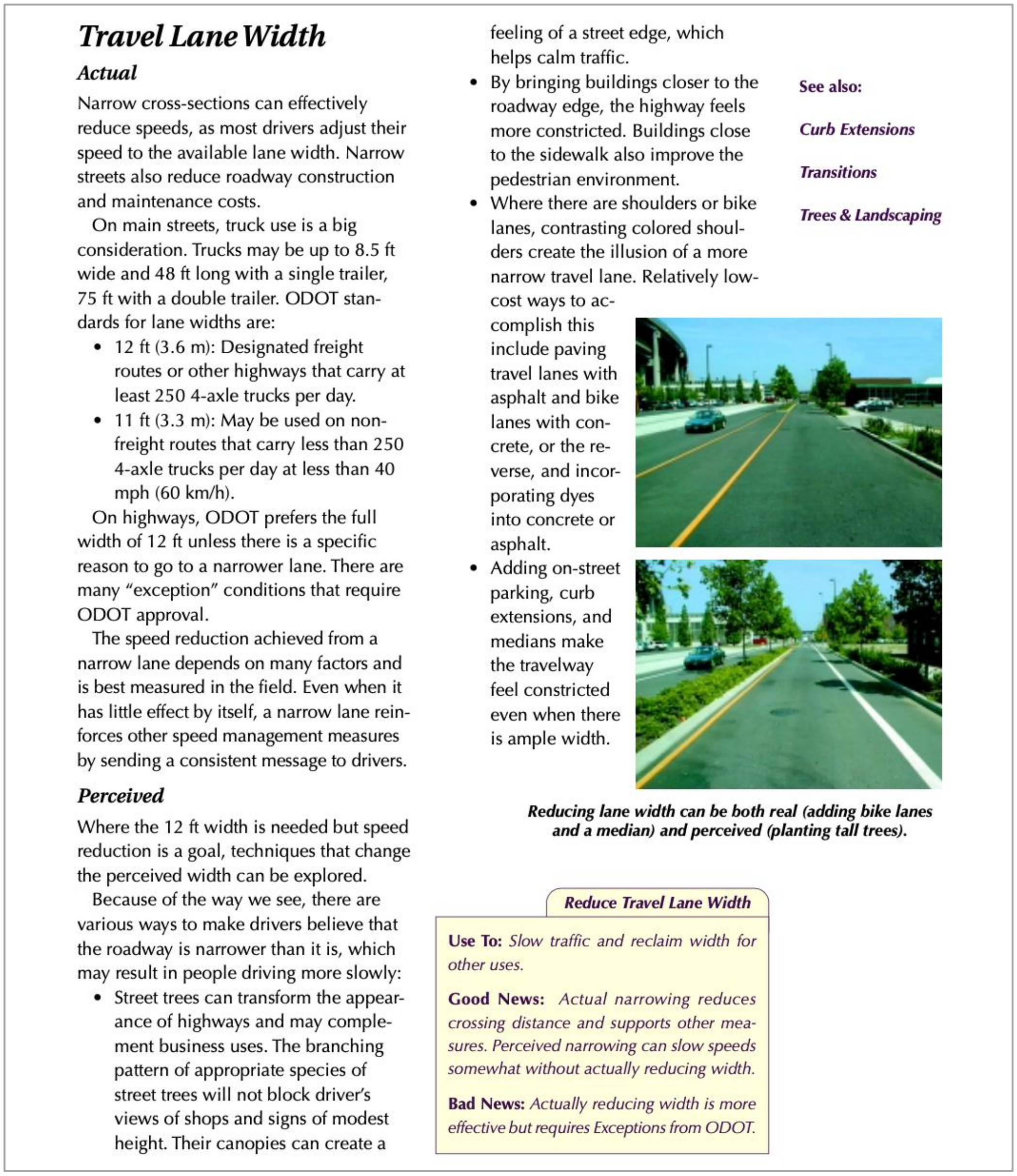
3.4.4 Blueprint for Urban Design

The Blueprint for Urban Design (BUD) was created in 2020 to incorporate the most current urban design criteria into ODOT designs as the urban design concepts evolved significantly between the 2012 version of the HDM and the 2023 update. The Blueprint was created as a "bridging document" to establish the revised criteria to be used when designing urban projects on the state system until all Oregon Department of Transportation manuals related to urban design were updated to include these revised design criteria, which happened with the implementation of the 2023 Highway Design Manual.

The Blueprint for Urban Design provides more guidance about how to appropriately apply some of the standards in HDM to get the most out of a corridor and meet the long-term goals of the corridor. The use of the Blueprint for Urban Design as the primary design document is required for all urban projects in the planning, scoping, or project initiation stages. Final approval of the Urban Design Concurrence document, which determines project context, defines design criteria and documents design decisions, is part of the final Design Acceptance Package process.

The BUD consists of two volumes. Volume One focuses on context and modal integration. It lays out the performance-based practice design policy for projects to follow. Its main purpose is to help project teams determine a context for the project design. Volume Two contains all the background information and some of the documentation. It is the design decision part where the cross section for the project is determined – both in terms of performance-based practical design and decision processes. It includes decision sections to document the design decision process that the project team went through to come up with a final cross section. Each project team is required to provide justifications for a specific dimension chosen from the range of dimensions recommended by the BUD.

The idea behind the BUD was to update a document that was created by the Transportation and Growth Management (TGM) program, a joint program of the ODOT and the Oregon Department of Land Conservation and Development (DLCD), in 1999: *Main Street - When a Highway Runs Through It. A Handbook for Oregon Communities*. The handbook proposed techniques to reduce the perceived lane width in cases where the 12-foot width is required or needed (Figure 3-14). The BUD builds on the ideas from the handbook but provides detailed design guidelines for six urban contexts, which were inspired by the National Cooperative Highway Research Program (NCHRP) Report 855: An Expanded Functional Classification System for Highways and Streets (Figure 3-15 and Figure 3-16).



Travel Lane Width

Actual

Narrow cross-sections can effectively reduce speeds, as most drivers adjust their speed to the available lane width. Narrow streets also reduce roadway construction and maintenance costs.

On main streets, truck use is a big consideration. Trucks may be up to 8.5 ft wide and 48 ft long with a single trailer, 75 ft with a double trailer. ODOT standards for lane widths are:

- 12 ft (3.6 m): Designated freight routes or other highways that carry at least 250 4-axle trucks per day.
- 11 ft (3.3 m): May be used on non-freight routes that carry less than 250 4-axle trucks per day at less than 40 mph (60 km/h).

On highways, ODOT prefers the full width of 12 ft unless there is a specific reason to go to a narrower lane. There are many "exception" conditions that require ODOT approval.

The speed reduction achieved from a narrow lane depends on many factors and is best measured in the field. Even when it has little effect by itself, a narrow lane reinforces other speed management measures by sending a consistent message to drivers.

Perceived

Where the 12 ft width is needed but speed reduction is a goal, techniques that change the perceived width can be explored.

Because of the way we see, there are various ways to make drivers believe that the roadway is narrower than it is, which may result in people driving more slowly:

- Street trees can transform the appearance of highways and may complement business uses. The branching pattern of appropriate species of street trees will not block driver's views of shops and signs of modest height. Their canopies can create a feeling of a street edge, which helps calm traffic.
- By bringing buildings closer to the roadway edge, the highway feels more constricted. Buildings close to the sidewalk also improve the pedestrian environment.
- Where there are shoulders or bike lanes, contrasting colored shoulders create the illusion of a more narrow travel lane. Relatively low-cost ways to accomplish this include paving travel lanes with asphalt and bike lanes with concrete, or the reverse, and incorporating dyes into concrete or asphalt.
- Adding on-street parking, curb extensions, and medians make the travelway feel constricted even when there is ample width.

See also:

Curb Extensions

Transitions

Trees & Landscaping

Reducing lane width can be both real (adding bike lanes and a median) and perceived (planting tall trees).

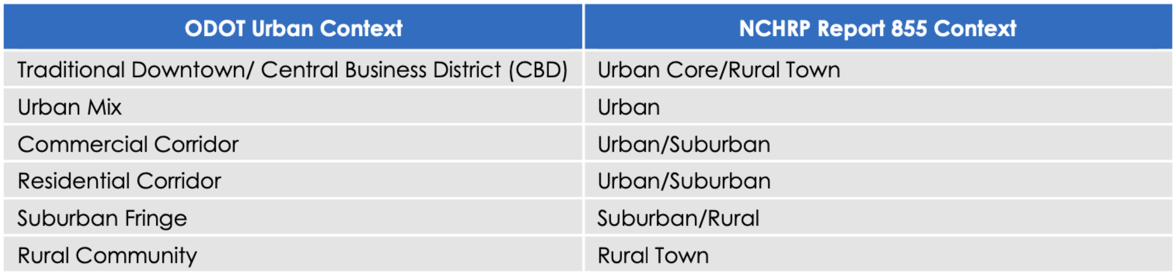
Reduce Travel Lane Width

Use To: *Slow traffic and reclaim width for other uses.*

Good News: *Actual narrowing reduces crossing distance and supports other measures. Perceived narrowing can slow speeds somewhat without actually reducing width.*

Bad News: *Actually reducing width is more effective but requires Exceptions from ODOT.*

Figure 3-14 Lane Width Guidelines from the 1999 "Main Street - When a Highway Runs Through It. A Handbook for Oregon Communities"



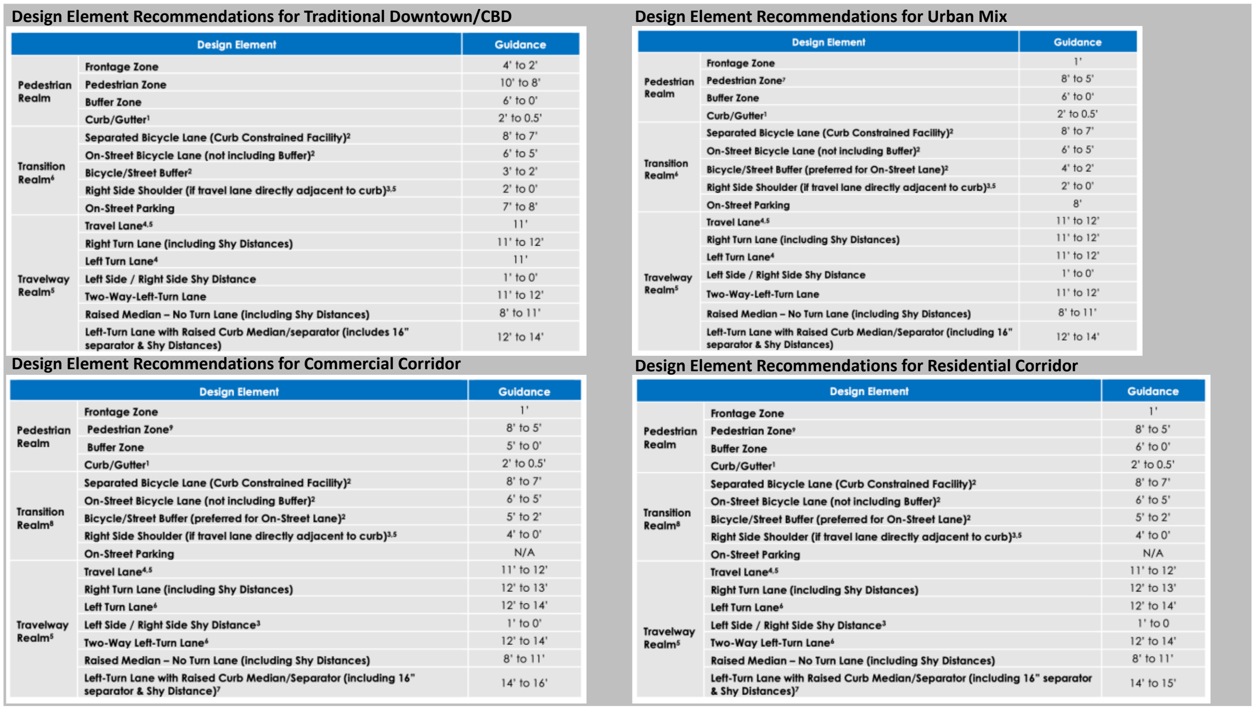
ODOT Urban Context	NCHRP Report 855 Context
Traditional Downtown/ Central Business District (CBD)	Urban Core/Rural Town
Urban Mix	Urban
Commercial Corridor	Urban/Suburban
Residential Corridor	Urban/Suburban
Suburban Fringe	Suburban/Rural
Rural Community	Rural Town

Figure 3-15 ODOT Urban Contexts

Figure 3-16 Lane Use Context

It is worth mentioning that the rural community context is intended for small mostly unincorporated communities that don't always fit into the federal classification numbers of 5,000 population to be urban but have many urban characteristics in them. Even though the roadways may be classified as rural arterials through such towns, they should not be designed as rural but instead the urban context should be adopted.

Each of the six urban contexts has been assigned a set of recommended design elements that include lane widths (Figure 3-17 and Figure 3-18). The recommended width of travel lanes is between 11 and 12 feet for all contexts but the Traditional Downtown/CBD context, where the recommended width is 11 feet.



Design Element Recommendations for Traditional Downtown/CBD

Design Element		Guidance
Pedestrian Realm	Frontage Zone	4' to 2'
	Pedestrian Zone	10' to 8'
	Buffer Zone	6' to 0'
	Curb/Gutter[1]	2' to 0.5'
Transition Realm[6]	Separated Bicycle Lane (Curb Constrained Facility)[2]	8' to 7'
	On-Street Bicycle Lane (not including Buffer)[2]	6' to 5'
	Bicycle/Street Buffer[2]	3' to 2'
	Right Side Shoulder (if travel lane directly adjacent to curb)[3,5]	2' to 0'
	On-Street Parking	7' to 8'
Travelway Realm[5]	Travel Lane[4,5]	11'
	Right Turn Lane (including Shy Distances)	11' to 12'
	Left Turn Lane[4]	11'
	Left Side / Right Side Shy Distance	1' to 0'
	Two-Way-Left-Turn Lane	11' to 12'
	Raised Median – No Turn Lane (including Shy Distances)	8' to 11'
	Left-Turn Lane with Raised Curb Median/separator (includes 16" separator & Shy Distances)	12' to 14'

Design Element Recommendations for Commercial Corridor

Design Element		Guidance
Pedestrian Realm	Frontage Zone	1'
	Pedestrian Zone[9]	8' to 5'
	Buffer Zone	5' to 0'
	Curb/Gutter[1]	2' to 0.5'
Transition Realm[8]	Separated Bicycle Lane (Curb Constrained Facility)[2]	8' to 7'
	On-Street Bicycle Lane (not including Buffer)[2]	6' to 5'
	Bicycle/Street Buffer (preferred for On-Street Lane)[2]	5' to 2'
	Right Side Shoulder (if travel lane directly adjacent to curb)[3,5]	4' to 0'
	On-Street Parking	N/A
Travelway Realm[5]	Travel Lane[4,5]	11' to 12'
	Right Turn Lane (including Shy Distances)	12' to 13'
	Left Turn Lane[6]	12' to 14'
	Left Side / Right Side Shy Distance[3]	1' to 0'
	Two-Way Left-Turn Lane[6]	12' to 14'
	Raised Median – No Turn Lane (including Shy Distances)	8' to 11'
	Left-Turn Lane with Raised Curb Median/Separator (including 16" separator & Shy Distance)[7]	14' to 16'

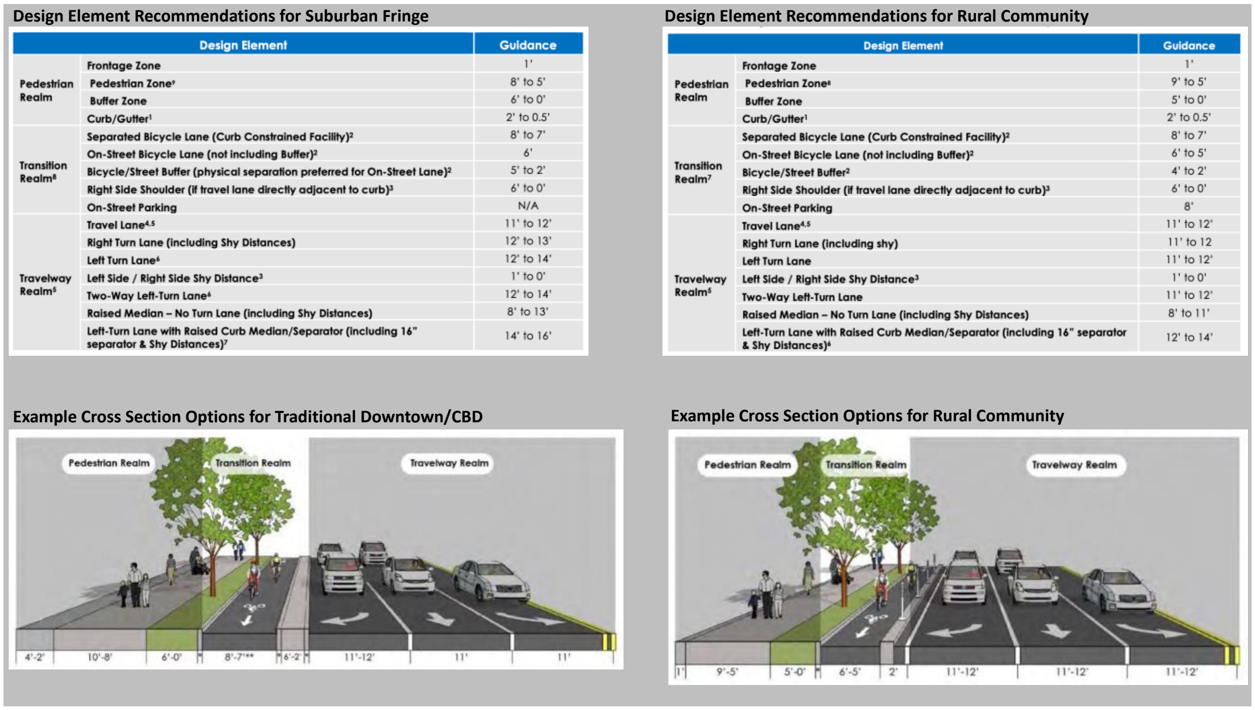
Design Element Recommendations for Urban Mix

Design Element		Guidance
Pedestrian Realm	Frontage Zone	1'
	Pedestrian Zone[7]	8' to 5'
	Buffer Zone	6' to 0'
	Curb/Gutter[1]	2' to 0.5'
Transition Realm[6]	Separated Bicycle Lane (Curb Constrained Facility)[2]	8' to 7'
	On-Street Bicycle Lane (not including Buffer)[2]	6' to 5'
	Bicycle/Street Buffer (preferred for On-Street Lane)[2]	4' to 2'
	Right Side Shoulder (if travel lane directly adjacent to curb)[3,5]	2' to 0'
	On-Street Parking	8'
Travelway Realm[5]	Travel Lane[4,5]	11' to 12'
	Right Turn Lane (including Shy Distances)	11' to 12'
	Left Turn Lane[4]	11' to 12'
	Left Side / Right Side Shy Distance	1' to 0'
	Two-Way-Left-Turn Lane	11' to 12'
	Raised Median – No Turn Lane (including Shy Distances)	8' to 11'
	Left-Turn Lane with Raised Curb Median/Separator (including 16" separator & Shy Distances)	12' to 14'

Design Element Recommendations for Residential Corridor

Design Element		Guidance
Pedestrian Realm	Frontage Zone	1'
	Pedestrian Zone[9]	8' to 5'
	Buffer Zone	6' to 0'
	Curb/Gutter[1]	2' to 0.5'
Transition Realm[8]	Separated Bicycle Lane (Curb Constrained Facility)[2]	8' to 7'
	On-Street Bicycle Lane (not including Buffer)[2]	6' to 5'
	Bicycle/Street Buffer (preferred for On-Street Lane)[2]	5' to 2'
	Right Side Shoulder (if travel lane directly adjacent to curb)[3,5]	4' to 0'
	On-Street Parking	N/A
Travelway Realm[5]	Travel Lane[4,5]	11' to 12'
	Right Turn Lane (including Shy Distances)	12' to 13'
	Left Turn Lane[6]	12' to 14'
	Left Side / Right Side Shy Distance[3]	1' to 0
	Two-Way Left-Turn Lane[6]	12' to 14'
	Raised Median – No Turn Lane (including Shy Distances)	8' to 11'
	Left-Turn Lane with Raised Curb Median/Separator (including 16" separator & Shy Distances)[7]	14' to 15'

Figure 3-17 BUD - Design Element Recommendations



Design Element Recommendations for Suburban Fringe

Design Element		Guidance
Pedestrian Realm	Frontage Zone	1'
	Pedestrian Zone[9]	8' to 5'
	Buffer Zone	6' to 0'
	Curb/Gutter[1]	2' to 0.5'
Transition Realm[8]	Separated Bicycle Lane (Curb Constrained Facility)[2]	8' to 7'
	On-Street Bicycle Lane (not including Buffer)[2]	6'
	Bicycle/Street Buffer (physical separation preferred for On-Street Lane)[2]	5' to 2'
	Right Side Shoulder (if travel lane directly adjacent to curb)[3]	6' to 0'
	On-Street Parking	N/A
Travelway Realm[5]	Travel Lane[4,5]	11' to 12'
	Right Turn Lane (including Shy Distances)	12' to 13'
	Left Turn Lane[6]	12' to 14'
	Left Side / Right Side Shy Distance[3]	1' to 0'
	Two-Way Left-Turn Lane[6]	12' to 14'
	Raised Median – No Turn Lane (including Shy Distances)	8' to 13'
	Left-Turn Lane with Raised Curb Median/Separator (including 16" separator & Shy Distances)[7]	14' to 16'

Design Element Recommendations for Rural Community

Design Element		Guidance
Pedestrian Realm	Frontage Zone	1'
	Pedestrian Zone[8]	9' to 5'
	Buffer Zone	5' to 0'
	Curb/Gutter[1]	2' to 0.5'
Transition Realm[7]	Separated Bicycle Lane (Curb Constrained Facility)[2]	8' to 7'
	On-Street Bicycle Lane (not including Buffer)[2]	6' to 5'
	Bicycle/Street Buffer[2]	4' to 2'
	Right Side Shoulder (if travel lane directly adjacent to curb)[3]	6' to 0'
	On-Street Parking	8'
Travelway Realm[5]	Travel Lane[4,5]	11' to 12'
	Right Turn Lane (including shy)	11' to 12
	Left Turn Lane	11' to 12'
	Left Side / Right Side Shy Distance[3]	1' to 0'
	Two-Way Left-Turn Lane	11' to 12'
	Raised Median – No Turn Lane (including Shy Distances)	8' to 11'
	Left-Turn Lane with Raised Curb Median/Separator (including 16" separator & Shy Distances)[6]	12' to 14'

Example Cross Section Options for Traditional Downtown/CBD

Example Cross Section Options for Rural Community

Figure 3-18. BUD – Design Element Recommendations

"We have suggested cross sections with flexibility in dimensions as opposed to absolute numbers. Our preferred mental calculation is 11 feet, but we have a range of 11 to 12 in the BUD because of our reduction review route needs in our negotiations and discussions with our freight community. We didn't go to 10 as a part of the range at the outset. Our chief engineer is not opposed to 10-foot lanes but doesn't want to have that as a flexibility option to just use. If you want to do a 10-foot lane, we would do that with a design exception based on appropriateness and based on route needs in those locations." (Rich Crossler-Laird, Senior Urban Design Engineer at Oregon Department of Transportation)

"*The state highway design perspective is a little different from a local jurisdiction perspective where they focus on their grid and their needs. The state has to consider the long term, longer distance mobility as well. We can't just allow 9-foot lanes on roads where 25% traffic is trucks. Decisions are made based on what is appropriate for a specific location. We rely on flexibility in decision-making processes at project levels*." (Rich Crossler-Laird, Senior Urban Design Engineer at Oregon Department of Transportation)

3.4.5. Design Criteria and Concurrence

The 2020 Blueprint for Urban Design and 2023 (combined) Highway Design Manual provide design guidelines (also called criteria) rather than prescriptive design standards. Each design element is assigned a recommended range of values (i.e., widths).

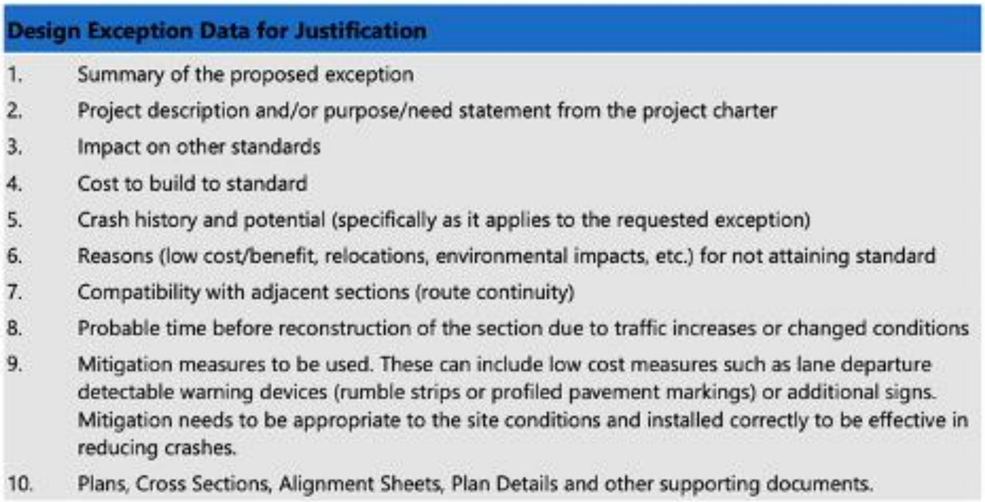
"*We're trying to move away from the term design standard and use the term design criteria. This broadens the spectrum a little bit when you're talking about what's the appropriate thing for this location, taking more things into account as opposed to just looking at the numbers. 12-foot travel lanes, 6-foot shoulders, 6-foot bike lanes, 12-foot median turns. Now we are allowing for a range that you can play within, but you need to justify why you chose a specific number within that range.*" (Rich Crossler-Laird, Senior Urban Design Engineer at Oregon Department of Transportation)

As part of ODOT's urban design approval process, projects are required to submit an Urban Design Concurrence Form in which project context is determined, project design criteria are defined, and project design decisions are documented. As mentioned before, the guidance provided in the HDM allows for a diverse range of potential designs. Therefore, for urban projects, the discretionary decisions of project teams must be documented. It is suggested to not only document what the project is accomplishing but also to document what isn't being done or can't be done with the specific project and why. This is particularly encouraged for preservation-type projects where the project scope is limited.

The majority of ODOT's projects fall into two categories of preservation projects - the typical 3R projects and a subcategory of 1R projects (true preservation projects designed simply to preserve the paving). For 3R projects, there is some leeway to install additional safety features (i.e., active transportation features or road diet elements). This opportunity is limited for the 1R project, however, even when only restriping, the number of lanes could be reduced from four to three, and a new bike lane put in if that makes an interim improvement to long-term goals and meets aspirational needs for the location.

3.4.6. Design Exceptions

Any deviation from lane width design standards (or criteria) outlined by the 2020 Blueprint for Urban Design or the 2023 ODOT Highway Design Manual requires a design exception. This means that projects including travel lane widths of less than 11 feet require additional approvals. Lane-width design exceptions are approved by the State Traffic-Roadway Engineer and require signatures from both the Engineer of Record (EOR) and the State Traffic-Roadway Engineer. In some cases, FHWA approval may also be required (i.e., “High Speed” NHS Roadways). Figure 3-19 shows the data required for design exception justification.



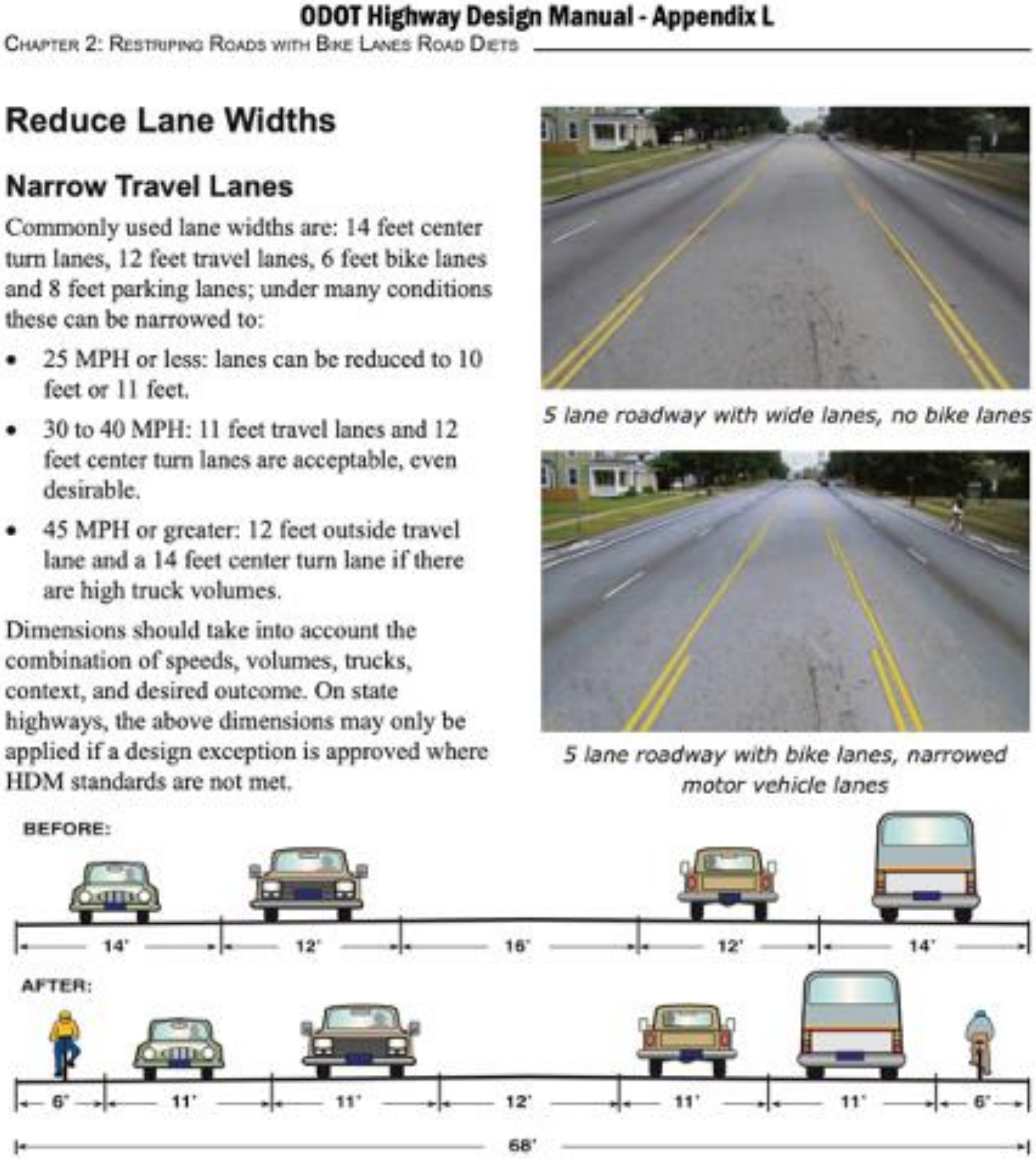
Design Exception Data for Justification

1. Summary of the proposed exception
2. Project description and/or purpose/need statement from the project charter
3. Impact on other standards
4. Cost to build to standard
5. Crash history and potential (specifically as it applies to the requested exception)
6. Reasons (low cost/benefit, relocations, environmental impacts, etc.) for not attaining standard
7. Compatibility with adjacent sections (route continuity)
8. Probable time before reconstruction of the section due to traffic increases or changed conditions
9. Mitigation measures to be used. These can include low cost measures such as lane departure detectable warning devices (rumble strips or profiled pavement markings) or additional signs. Mitigation needs to be appropriate to the site conditions and installed correctly to be effective in reducing crashes.
10. Plans, Cross Sections, Alignment Sheets, Plan Details and other supporting documents.

Figure 3-19 Data Required for Design Exceptions

3.4.7. Oregon Bicycle and Pedestrian Design Guide

The Oregon Bicycle and Pedestrian Design Guide is an integral part of the 2023 ODOT Highway Design Manual (Appendix L). It provides guidelines illustrating how a roadway can be restriped for bike lanes without negatively affecting and even enhancing the safety and operation of the roadway. For example, it suggests that with 32 feet available, there are at least three possible ways of restriping to provide a bike lane. 10.5-foot travel lanes with 5.5-foot bike lanes, 11-foot travel lanes with 5-foot bike lanes, or 10-foot travel lanes with 6-foot bike lanes. The choice of width for both travel lanes and bike lanes depends on the context and is project specific. A summary of how to add bike lanes by narrowing travel lanes is provided in Figure 3-20.



ODOT Highway Design Manual - Appendix L

CHAPTER 2: RESTRIPING ROADS WITH BIKE LANES ROAD DIETS

Reduce Lane Widths

Narrow Travel Lanes

Commonly used lane widths are: 14 feet center turn lanes, 12 feet travel lanes, 6 feet bike lanes and 8 feet parking lanes; under many conditions these can be narrowed to:

- 25 MPH or less: lanes can be reduced to 10 feet or 11 feet.
- 30 to 40 MPH: 11 feet travel lanes and 12 feet center turn lanes are acceptable, even desirable.
- 45 MPH or greater: 12 feet outside travel lane and a 14 feet center turn lane if there are high truck volumes.

Dimensions should take into account the combination of speeds, volumes, trucks, context, and desired outcome. On state highways, the above dimensions may only be applied if a design exception is approved where HDM standards are not met.

5 lane roadway with wide lanes, no bike lanes

5 lane roadway with bike lanes, narrowed motor vehicle lanes

Figure 3-20 Adding Bike Lanes by Narrowing Travel Lanes

3.5. ***California Department of Transportation (Caltrans)***

3.5.1. Background

The California Department of Transportation (Caltrans) aims to deliver integrated walking, biking, transit, and passenger rail through a world-class transportation network, providing comfortable, convenient, and connected complete street facilities for all. In 2020, the California Department of Transportation (Caltrans) defined the minimum lane width on two-lane and multilane highways, ramps, collectors, distributor roads, and other appurtenant roadways as 12 feet with a few exceptions in their Highway Design Manual (Index 301.1). One exception to the 12-foot-lane width is an 11-foot minimum lane for conventional state highways with posted speeds less than or equal to 40 miles per hour and AADTT (truck volume) less than 250 per lane located in urban, city, or town centers, and rural main streets. Moreover, in section 405.3 of the Highway Design Manual, for right-turn channelization in urban, city, or town centers (and rural main streets) with posted speeds less than 40 miles per hour in severely constrained situations and low truck or bus volume, consideration has been given to reducing the right-turn lane width to 10 feet. So, the lane width is flexible in certain contexts.

Many projects, such as road diets, reducing lanes for cycle tracks, squeezing in bike lanes in the constrained right-of-way, and compact urban roundabouts with a road diet, have been initiated in district 6 of California. Though Caltrans already has a 12-foot standard lane width, 11 feet is possible with a design exception (approval of Design Standard Decision Document DSDD). At one time, these design exceptions had to be approved by headquarters. However, recently it has been made much easier as design exceptions can be approved at the district level for conventional highways, whereas for freeways, approvals still need to come from higher authority. Cost-benefit analysis is also needed when it comes to approval of design exceptions. The adjusted space from reducing lane width has been repurposed for “buffer bike lanes” of more than 5 feet, ensuring bike users' safety.

However, this lane reduction is not applied everywhere, as a few Caltrans districts disapprove of bicycle lanes on state highways with high-speed traffic because of safety concerns. If there is a certain number of trucks on the highways, the outside lanes may still affect road capacity, speed, and safety and simultaneously create conflicts.

Caltrans also adopted lane purposing or road diets where lane width can be reduced, the layout can be changed to create more space, and the extra space can be reassigned for other purposes. In Madera, California, a road diet project on Highway 145 reduced four lanes to two lanes with a center two-way turn lane and created space for other facilities. As the level of service is no longer considered a primary performance measure for roads in California, Caltrans started considering compact development, traffic calming, vehicle miles traveled, and roundabouts as performance measures and methods. Caltrans considers bike lanes, on-street parking (preferably reversed-angle parking), and a green pit for the buffer area created by the road diet. Some cities also consider buffer areas for sidewalks. Though design exceptions are driven by cost savings mostly, place making is also considered in design exceptions. Caltrans focuses on creating complete streets, and evidence shows that 10-feet or 10.5-feet road lanes have been functioning well without any significant speed reduction or increased crash incidents.

3.5.2. Caltrans Highway Design Manual

In 2020, the Highway Design Manual was revised by the Division of Design for use on the California state highway system. Uniform policies and procedures have been established to carry out state highway design functions for the department. According to the Highway Design Manual, during the project development process, the project's different effects, such as social, economic, and environmental effects, must be considered fully along with technical issues so that final decisions can be made in the public interest. Special attention is given to providing transportation for all facility users, attainment of community goals, needs of low mobility and disadvantaged groups, and costs and benefits of eliminating or minimizing adverse effects on natural resources. Bearing this in mind, the manual also introduces standard lane widths with exceptions.

Index 301.1 of the manual discusses the standard of lane width with exceptions. According to the manual (Index 301.1), “The minimum lane width on two-lane and multilane highways, ramps, collector distributor roads, and other appurtenant roadways shall be 12 feet.” The exceptions to the rule are as follows.

- “*For conventional State highways with posted speeds less than or equal to 40 miles per hour and AADTT (truck volume) less than 250 per lane that are in urban, city or town centers (rural main streets), the minimum lane width shall be 11 feet. The preferred lane* *width is 12 feet. Where a 2-lane conventional State highway connects to a freeway within an interchange, the lane width shall be 12 feet. Where a multilane State highway connects to a freeway within an interchange, the outer most lane of the highway in each direction of travel shall be 12 feet.*

- *For highways, ramps, and roads with curve radii of 300 feet or less, widening due to off tracking in order to minimize bicycle and vehicle conflicts must be considered."*

Another exception of lane width for roads under other jurisdictions, such as city streets and county roads, is design exceptions which are outlined in Index 308.1.

Moreover, consideration has been given to both left-turn and right-turn channelization. According to Index 405.2 of the Highway Design Manual, in left-turn channelization, "*the lane width for both single and double left-turn lanes on State highways shall be 12 feet. For conventional State highways with posted speeds less than or equal to 40 miles per hour and AADTT (truck volume) less than 250 per lane that are in urban, city or town centers, and rural main streets, the minimum lane width shall be 11 feet*." However, in Index 405.3 of the Highway Design Manual, for "right-turn channelization in urban, city or town centers (rural main streets) with posted speeds less than 40 miles per hour in severely constrained situations, if truck or bus use is low, consideration may be given to reducing the right-turn lane width to 10 feet."

3.5.3. Lane Narrowing Projects

State Route 63 (Mooney Blvd, California) Redesign

One of the visions of Caltrans is to eliminate fatalities and severe injuries on California's roadways by 2050 and provide safer outcomes for all communities. Following this, Caltrans considers safe road users, safe vehicles, safe speeds, safe roads, proactive safety, and post-crash care as elements of a safe system approach. The State Route 63 project was initiated to meet the requirements of a safe street, especially safe bike lanes.

State Route 63 (SR 63) is a north-south state highway in the Central Valley, starting adjacent to Tulare at Route 137, running north through the city of Visalia and the towns of Cutler and Orosi, and then ending 8 miles (13 km) north of Orange Cove. The main objective of the State

Route 63 project is to provide continuously dedicated bike lanes and ensure the safety of bicyclists. Previously this state highway had typical 5-foot bike lanes, green paint placed in conflict areas, and arrows (shared lane markings) placed in right-turn lanes, which were too narrow for a bike lane and unsafe for bike users (Figure 3-21).

Figure 3-21 Previous Bike Lanes on State Route 63

Figure 3-22 depicts the existing and proposed bike lane, bike route, cycle track, and shared used path in the Visalia Active Transportation Plan. Figure 3-23 also depicts the project area map where construction starts on a 2.2-mile segment of Mooney Blvd from 0.2 miles south of Caldwell Avenue to SR-198. The construction cost is estimated at $11.8 million and is scheduled for the fall of 2023. In this project, 1.8 inches of asphalt pavement needs to be removed and replaced. Other project components include upgrading traffic signals, installing sign panels, and providing curb ramps. Proposed 5-foot Class II bike lanes will also be added by narrowing travel lanes from 12 feet to 10-11 feet, with green paint in conflict areas.

Figure 3-22 Visalia Active Transportation Plan

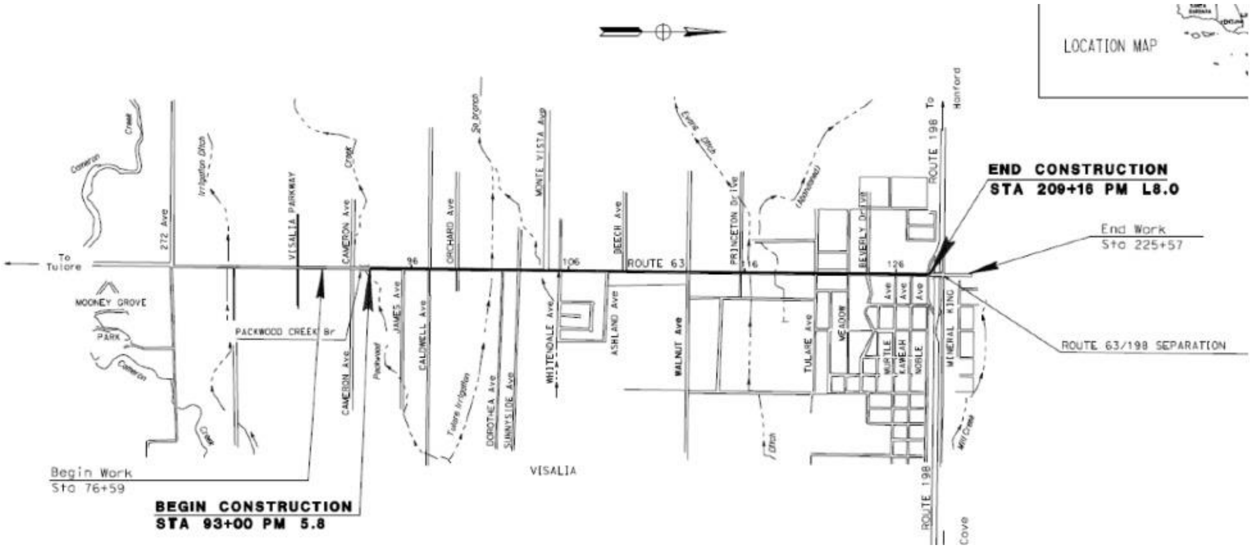


Figure 3-23 SR 63 Mooney Road

Existing Designs

Proposed Designs

Figure 3-24 SR 63 Mooney Blvd Before and After the Project

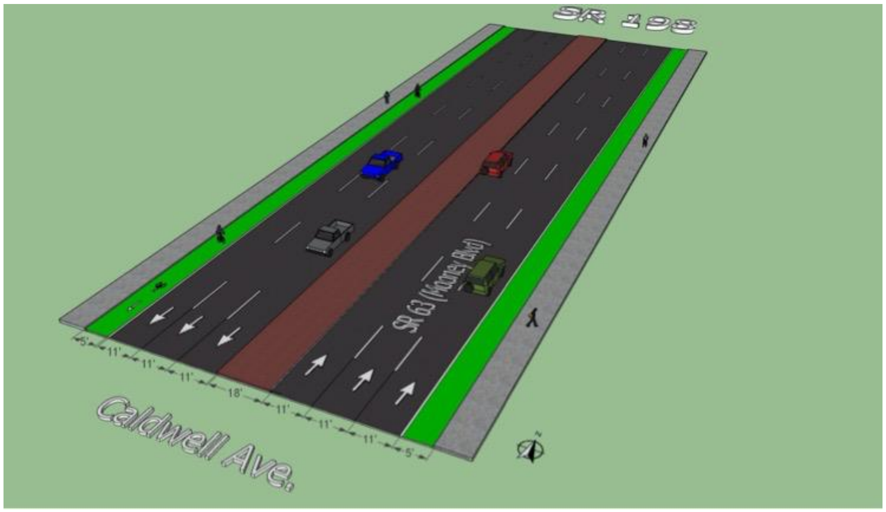


Figure 3-25 SR 63 Mooney Blvd Proposed Design

Figure 3-26 SR 63 N Dinuba Blvd Bike Lanes Proposed Design

Figure 3-26 depicts proposed bike lanes for the 0.8-mile segment of N Dinuba Blvd from W Houston Avenue to W Robin Drive. In this road segment, travel lanes will be narrowed from 12 feet to 10 or 11 feet in order to provide 5-foot Class II bike lanes with green paint in conflict areas. The construction work was expected to start in the fall of 2022 or spring of 2023.

State Route 145 Pavement Project and Complete Street

Caltrans considers all types of transport, including walking, biking, transit, and passenger rail, in an integrated way to provide a world-class transportation network. Caltrans also recognizes streets as valuable community spaces; therefore, all projects initiated by Caltrans aim to provide comfortable, convenient and connected complete streets for all. The State Route 145 pavement project has been initiated to extend the pavement life from Avenue 13 to the East Madera Underpass Bridge, as well as to implement the complete street policy of Caltrans (Figure 3-27). The estimated construction cost of this project is around $13.4 million (including $4 million for complete street enhancements), and the construction work is expected to take place from Fall 2024.

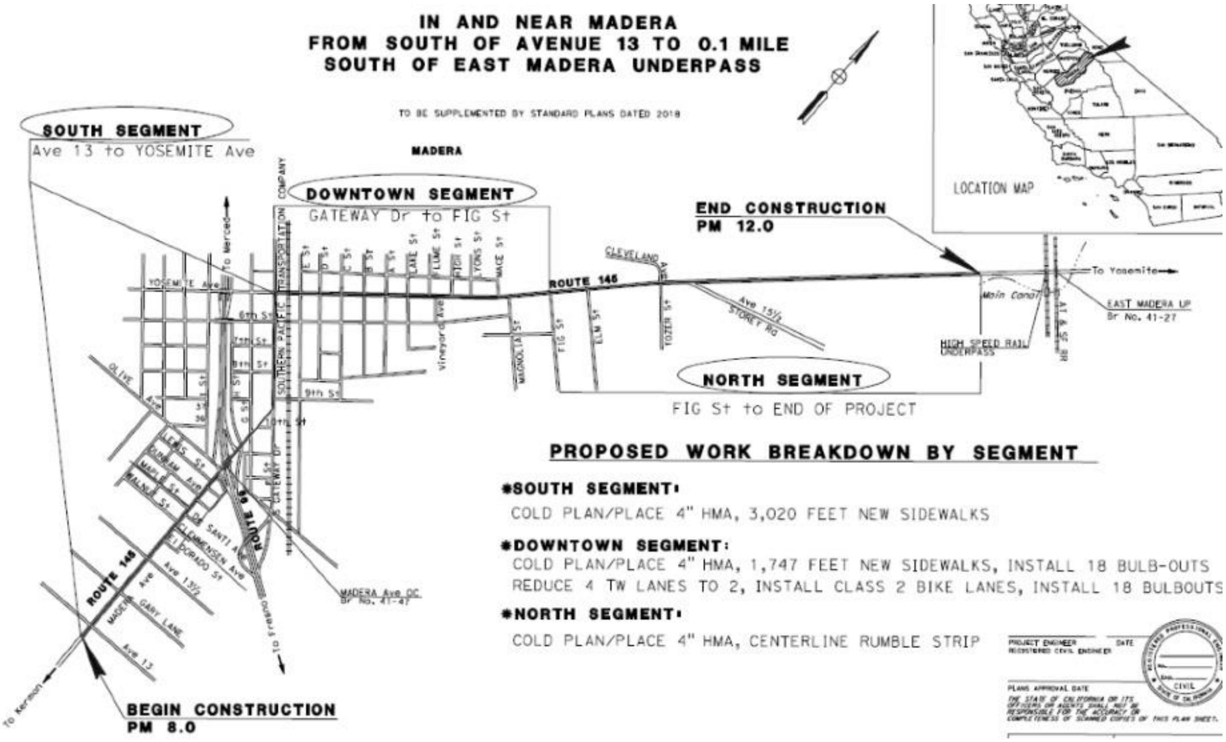


Figure 3-27 State Route 145 Project Location

The scope of this project is:

- Remove and replace about 4 inches of pavement
- Install or upgrade curb ramps
- Install bicycle facility, bike parking, and bulb-outs
- Install transit stops
- Upgrade traffic signal components

The project also incorporates the following safety system principles:

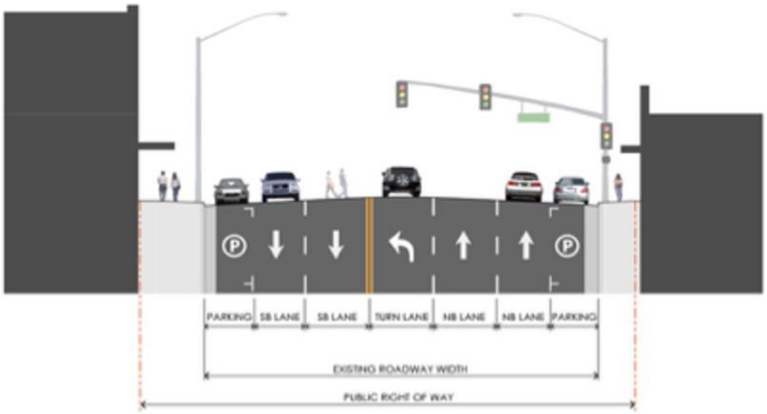
- Death/serious injury is unacceptable
- Humans make mistakes
- Humans are vulnerable
- Responsibility is shared
- Safety is proactive
- Redundancy is crucial

In 2020, the Madera City Council decided that diversion of traffic, traffic mitigation, potential relinquishment or gateway drive to Lake Street, and parking provisions should be part of the project.

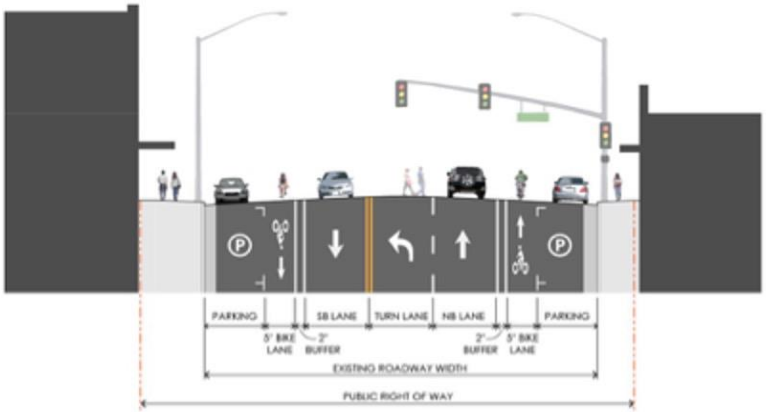
Existing Designs

Proposed Designs

Figure 3-28 Downtown C Street with Traffic Diversion



Existing Designs



Proposed Designs

Figure 3-29 Cross Section of Downtown C Street

Existing Designs

Proposed Designs

Figure 3-30 Bike Lanes at Yosemite Ave Between Lyons St & Mace St

Existing Designs

Proposed Designs

Figure 3-31 Footpath at S. Madera Ave Between G St & Gateway

Figure 3-32 Narrowing Lane From Lake Street to Vineyard Avenue

The proposal would retain a traffic signal in the Lake Street option and provide two through lanes in each direction. The proposal also includes narrowing lanes to 11 feet to add 5-foot bike lanes. Possible roundabout options have been considered where applicable. The existing speed limit on this road is 45 miles per hour. Caltrans is going to measure the 85th percentile speed after the completion of the project in order to justify a possible reduction in the speed limit.

3.5.4. Design Exceptions

For the design features that deviate from the design standards in the Highway Design Manual, Caltrans developed Design Standard Decision Documentation (DSDD) which guides documenting such engineering decisions. The approval authority of the DSDD belongs to the Headquarters Project Delivery Coordinator for some of the nonstandard design features and the District Director for others. The documentation includes a project description, general highway characteristics, the facility’s classification, safety improvements, and total project cost. It also includes general information such as the design standard, nonstandard features and reason for not using the design standard plus the added cost to meet the standard, and design features.

3.5.5. Traffic Calming Guidance

Caltrans considers all modes of travel essential for providing a world-class transportation network through improved accessibility and connectivity to crucial community destinations, providing livability and safety to all users of the state highway system. Even though the Federal Highway Administration (FHWA) dictates the use of traffic control devices through the Manual on Uniform Traffic Control Devices, and the state acts accordingly, sometimes the goal of orderly and safe movement of traffic is compromised by excessive speeds of certain drivers. Caltrans employs traffic calming techniques for slowing down speeding vehicles.

According to the FHWA Traffic Calming Primer. “*The primary purpose of traffic calming is to support the livability and vitality of residential and commercial areas through improvements in non-motorist safety, mobility, and comfort. These objectives are typically achieved by reducing vehicle speeds or volumes on a single street or a street network. Traffic calming measures consist of horizontal, vertical, lane narrowing, roadside, and other features that use self-enforcing physical or psycho-perception means to produce desired effects.*”

According to Caltrans, conventional highways are the target of traffic calming, and several strategies, such as law enforcement, public education, and temporary and permanent speed calming highway infrastructure, can be considered effective. The need for traffic calming can be determined by several measures, such as existing operating vehicular speeds, volume counts, number of crashes, and adjacent land uses.

3.6. ***Delaware Department of Transportation***

3.6.1. Background

From the Delaware Road Design Manual, DelDOT has based its road design regulations on the AASHTO Green Book and tries to remain consistent with it. The typical lane width in Delaware is between 10 to 12 feet, which complies with the Green Book. The design guidelines for lane width, promulgated by DelDOT, state that:

> *"For new construction and reconstruction projects, 12-foot lanes should be used on roadways with design speeds of 55 mph or greater, and 11-foot travel lanes should be used on roadways with design speeds from 35 mph to 50 mph. Ten-foot travel lanes should be used on roadways with design speeds below 35 mph with consideration for 11-foot lanes that are adjacent to bike lanes. Ten-foot travel lanes should … be avoided along transit routes and roadways with heavy truck traffic."*

Keeping this project's guidelines in mind, based on the project's needs, the best lane width varies, and engineering judgment must be used case by case. In new projects, most designs start from a 12-foot lane and adjust the lane width to find the suitable value based on existing conditions. Therefore, reducing to an 11-foot lane would not be considered a design exception and is suggested by DelDOT based on road conditions. Due to the geographical nature of Delaware and its intensive transportation network, most roadways have narrow passages. The latter raises the need for redesign in some cases to save more space for a new facility or change of utilization purpose. As a result, reducing lane widths from 12 to 11 feet will save extra space for other purposes, such as bike lanes. The key point for reducing lane width being feasible in a road design is the "delivery" of the project.

The extra space from lane width reduction can be used for multiple purposes depending on the context of the project. For instance, in pavement rehab projects, the additional space is mainly assigned to broader shoulders or bike lanes. If a road diet is in an urban area, the added space might also be used for parking. In some intersection improvement projects, there might be the need for a left- or right-turn lane, where reducing a foot from through travel lanes can help save space and include extra lanes. Adding extra lanes here will improve the roadway's capacity.

In our interview with DelDOT, a question about the difference between 11- and 12-foot lanes on traffic networks was also raised. Engineers at DelDOT believe there is no significant difference in traffic operational parameters, including crash and speed, with 11- versus 12-foot lanes. Also, from the driver's perspective, there might be no noticeable difference with a 1-foot lane width reduction. It was stated that "No complaints were ever submitted on having 'too narrow' lanes." It was noted that reducing lane width to 10 feet might also show minimal changes in speed. On the other hand, in cases with high truck volume or high-speed corridors, using 12-foot lanes might be a better choice. Most 11-foot lanes are in suburban or rural areas with speed limits of less than 35 mph. 10-foot lanes are not often used in Delaware and are primarily found in rural areas. Based on feedback from transit agencies, 10-foot lanes restrict movement of transit vehicles.

3.6.2. DelDOT Road Design Manual

DelDOT has developed the Road Design Manual to ensure safety and effective roadway designs. The manual follows the principal national documents, including AASHTO, HCM, MUTCD, and Flexibility in Highway Design. The objective of road design guidelines is to create roads that are consistent and predictable for drivers. Road functional classification, design controls, design elements, and cross-section elements are required to be determined in the early stages of project development. Meanwhile, picking the proper design controls relevant to LOS, safety, economics, and context is necessary for each design project. The standard offered by the design manual is based chiefly on ranges from the AASHTO Green Book; however, in some cases, there might be values lower than recommended by AASHTO, which typically happens on lower functionally classified roads. Such design exceptions should be determined in the early stages of projects and require documentation and approval by the chief engineer. Meanwhile, new construction and reconstruction projects are expected to follow the standard guidelines.

The desired lane width for all new construction and reconstruction is 12 feet. However, on low-speed roadways with low truck volumes and no safety concerns, 11-foot lanes can be used. 11-foot lane widths are used particularly in urbanized areas with limited right-of-way and increased pedestrian activity. At higher speeds, a 12-foot lane width is suggested on urban arterials with free flow conditions. On local roads, 11 feet is allowed, although where there are truck and vehicular volumes with low operating speeds, a lane width of even 9 or 10 feet can be used. Delaware is one of the few states that owns and operates functionally classified local roads. Design speed is the primary element in picking the best-paved lane width.

At the time of our interview, DelDOT was in the process of releasing its new roadway design manual that, compared to older versions, has not changed in most respects. However, based on design guidelines in the new manual, the default lane width is considered 11 feet. This can be viewed as a remarkable change since, as in previous manuals, an 11-foot lane was considered only "acceptable" under specific conditions. On the other hand, the newest guideline specifies the road classifications on which an 11-foot lane can be used.

One of the motives of DelDOT in updating its practices and guidelines is to reduce speed and facilitate a safe and efficient traffic flow in the traffic network. Reducing lane width is claimed to be one of these approaches. Additionally, DelDOT has implemented multiple "Road Diet" or "Road Reconfiguration" projects. Based on the network performance analysis, the speed and crash rates of the corridors have been reduced due to the new layout of the roadways. Among lane width reduction projects, they have done a pavement rehab project to add extra bike lanes within a corridor.

3.6.3. Delaware Traffic Calming Design Manual

Delaware's Traffic Calming Design Manual was written by Professor Reid Ewing at the University of Utah and first adopted in 2000, and later updated in 2011 by DelDOT to provide guidance and set standards for establishing traffic calming measures in Delaware. The applicability of this manual is restricted to local roads and subdivision streets with posted speed limits less than or equal to 35 miles per hour. Major arterials, collectors, and state-maintained roads with posted speed limits beyond 35 miles per hour are not eligible for traffic calming measures outlined in this manual. Following the guidelines outlined in the manual, DelDOT undertook several traffic calming projects starting in August 2000.

In the manual, striping (a non-construction measure) is described as “*a means of controlling speed including measures to* ***effectively narrow the travel lanes to encourage lower speeds****, to emphasize pedestrian crossings, or to supplement signing regulations (such as existing stop signs). Striping, which can be used in traffic calming, includes centerline stripes, edge line stripes, crosswalks, and stop bars at existing stop signs*.”

4.0 BEST PRACTICE REVIEW

Besides interviewing the selected DOTs, other available practices and standards were reviewed. The summary of these practices on lane width design are as follows.

4.1. AASHTO Green Book

We reviewed A Policy on Geometric Design of Highways and Streets (7th edition) otherwise known as the AASHTO Green Book, which outlines geometric design guidelines for all roads and streets for all modes of transportation based on recent research. According to AASHTO Green Book,

"Lane widths on through-travel lanes may vary from 10 to 12 ft [3.0 to 3.6 m]. Lane widths of 10 ft [3.0 m] may be used in more constrained areas where truck and bus volumes are relatively low and speeds are less than 35 mph [60 km/h]. Lane widths of 11 ft [3.3 m] are used quite extensively for urban arterial street designs. The 12-ft [3.6-m] lane widths are desirable, where practical, on high-speed, free-flowing, principal arterials." (page 7-39)

The key takeaways are:

- 10- to 12-foot lanes are suggested (12-foot lane width reduces costs of shoulder and maintenance and is primarily used on principal arterials. Also, lanes as narrow as 9 feet can be used on local roads),
- Auxiliary lanes cannot be less than 10 feet,
- 10-foot lanes are used for low-truck volume areas with a speed design of less than 35 mph,
- Narrower lanes will help reduce operating speed, increase pedestrian safety, and reduce costs.[3]

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[3] The Green Book states: "In urban areas, the land use context and presence of nonmotorized users may suggest that an arterial be designed to effectively limit the resultant operating speeds on the facility to best balance the needs of all users. FHWA guidance states that '…in urban areas, the design of the street should generally be such that it limits the maximum speed at which drivers can operate comfortably, as needed to balance the needs of all users.' In those situations, there are several choices in the selection of design elements and criteria for arterials in urban areas that can induce speed reductions and have other operational and crash reduction benefits for all road users. These include reduced lane widths, lane reductions, curb extensions, center islands or medians, on-street parking, and special intersection designs such as roundabouts. All of these speed management design techniques can be implemented on low-speed arterials and some may also be appropriate on high-speed roadways."

4.2. ITE/CNU[4] Recommended Practice

The Congress for the New Urbanism collaborated with the Institute of Transportation Engineers (ITE) to outline guidebooks such as 'Designing Walkable Urban Thoroughfares: A Context-Sensitive Approach' and 'Implementing Context-Sensitive Design on Multimodal Corridors: A Practitioner's Handbook.' The recommended practices are:

- Lane width is affected by the design vehicle and functional class,
- Minimum 10-foot lanes can be accommodated in low-speed areas (25 to 30 mph),
- Adjacent minimums cannot be combined (lane width and parking lane),
- Lane width: (less than 35 mph) 10- to 12-feet for arterials, 10- to 11-feet for collectors; the higher the speed limit, the higher end of the design limit is used and vice versa,
- The truck and bus percent in roadway and road curves also affect lane width,
- Sufficient bicycle/parking lane width is required for expanding lane width.

4.3. NCHRP Synthesis 324

This report is an outcome of research conducted as a part of the National Cooperative Highway Research Program by TRB:

- 11- to 12-foot lanes recommended for roadways,
- No specific relationship between safety (crash rates) and lane width is found in studies.

4.4. NCHRP Report 783

This report is also an outcome of research conducted as a part of the National Cooperative Highway Research Program at TRB:

- Lane width is shown not to affect traffic speed in urban and suburban areas,
- The geographical region has a significant effect on traffic speed change by lane width change,
- Design exceptions are best applied to lanes less than 11 feet.

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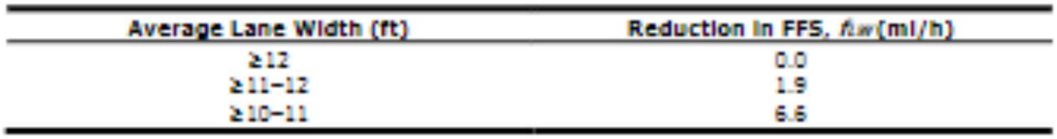
[4] Institute of Transportation Engineers / Congress for the New Urbanism

4.5. Highway Capacity Manual, 7th Edition

The Highway Capacity Manual 2022 (7th edition) provides guidelines to reduce the free flow speed of multilane highways (NASEM and TRB, 2022). A lane width of 12 ft or greater has been considered the base condition, while the Free Flow Speed of the Multilane Highway Segment (FFS) is negatively affected (NASEM and TRB, 2022).



Average Lane Width (ft)	Reduction in FFS, f_{LW} (mi/h)
≥12	0.0
≥11–12	1.9
≥10–11	6.6

Figure 4-1 HCM Suggested Adjustment of Lane Width for Reduction in FFS

4.6. NACTO Urban Street Design Guide

The National Association of City Transportation Officials produced the Urban Street Design Guide to provide guidelines focusing on the unique demands in an urban context. The guide has become an important reference for traffic engineers in progressive cities. The key recommendations are:

- 10-foot lanes are recommended for safety, while wider lanes than 11 feet are not recommended due to unintended speed,
- Additional lane width is required at tight curves due to more horizontal occupied space in turning movements,
- Wider lanes may be required for truck passage.

5.0 SURVEY OF AASHTO COMMITTEE ON DESIGN MEMBERS

5.1. Background

Our team conducted a survey of members of the American Association of State Highway and Transportation Officials (AASHTO), which publishes specifications, test protocols, and guidelines used in highway design and construction throughout the United States. Specifically, the survey was sent to members of AASHTO's Committee on Design. This survey aimed to explore lane width reduction projects across the United States and their associated impacts, including traffic safety, vehicle speed, and vehicle and pedestrian volumes. While reducing vehicle lane width is often considered a way to decrease vehicle speed and increase road safety, comprehensive knowledge is lacking on practices and their impact. Thus, by eliciting responses from the AASHTO committee, we expected to better understand current practices, identify exemplary projects, and gain insights into the costs and benefits of lane narrowing projects.

5.2. Summary of Responses

Survey responses were received from 13 individual members of the AASHTO committee (refer to the appendix for the names and contact information of these members). The survey questionnaire was divided into three (3) sections, with each section providing detailed insights into the above. The first section inquired about roadway design standards employed by the surveyed states, whereas the second section asked about lane-width reduction projects within their jurisdictions. The final section collected committee members' contact information, affiliations, and interest in the final survey results.

All (100%) respondents to the survey questionnaire indicated that they have statewide roadway design standards, manuals, and policies that regulate vehicle lane widths and/or limit the reduction of vehicle lane widths. Probing further to identify the details of these standards, manuals, and policies revealed document sources. A detailed list of reference documents is provided in Table 5-1 .

Table 5-1 Statewide Roadway Design Standards, Manuals, and Policies Adopted by AASHTO Members

AASHTO Committee Member	Adopted Roadway Design Standards, Manuals, And Policies	Reference
Michigan DOT	▪ Michigan Road Design Manual	https.//mdotjboss.state.mi.us/stdplan/englishroadmanual.htm
Ohio DOT	▪ Location and Design Manual Volume	https.//www.transportation.ohio.gov/working/engineering/roadway/manuals-standards/location-design-vol-1/
Alabama DOT	▪ ALDOT Performance Based Practical Design Guide ▪ AASHTO Green Book ▪ Highway Safety Manual	https.//www.dot.state.al.us/publications/Design/pdf/PerformanceBasedPracticalDesignGuide.pdf
Maine DOT	▪ Engineering Instructions for Roadway Design	https.//www.maine.gov/tools/whatsnew/attach.php?id=815852&an=1
California DOT	▪ Highway Design Manual ▪ DIB 79 Design Guidance and Standards for 3R Projects	https.//dot.ca.gov/programs/design/manual-highway-design-manual-hdm https.//dot.ca.gov/programs/design/design-information-bulletins-dibs/dib-79-04
Tennessee DOT	▪ RD11-TS-Series	https.//www.tn.gov/content/tn/tdot/roadway-design/standard-drawings-library/standard-roadway-drawings/roadway-design-standards.html
Washington State DOT	▪ Design Manual M 22-01	https.//www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/design.pdf
Minnesota DOT	▪ MnDOT Road Design Manual ▪ Geometric Design and Layout Development ▪ Bicycle Facility Design Manual	https.//roaddesign.dot.state.mn.us/roaddesign.aspx https.//roaddesign.dot.state.mn.us/facilitydesign.aspx http.//www.dot.state.mn.us/design/geometric/resources.html
Alaska DOT	▪ Highway Preconstruction Manual ▪ AASHTO Green Book	https.//dot.alaska.gov/stwddes/dcsprecon/preconmanual.shtml
Arizona DOT	▪ Roadway Design Standards and Guidelines ▪ Roadway Design Memorandums ▪ Construction Standard Drawings	https.//azdot.gov/business/engineering-and-construction/roadway-engineering/roadway-design/roadway-design-guidelines
Montana DOT	▪ Road Manual and Guide ▪ Baseline Criteria Practitioners Guide ▪ MDT Geometric Design Criteria and Design Exceptions	https.//www.mdt.mt.gov/publications/manuals.aspx#rdm https.//www.mdt.mt.gov/business/consulting/design-memos.aspx

AASHTO Committee Member	Adopted Roadway Design Standards, Manuals, And Policies	Reference
Kentucky DOT	▪ Highway Design Guidance Manual	https.//transportation.ky.gov/Organizational-Resources/Policy%20Manuals%20Library/Highway%20Design.pdf
Texas DOT	▪ Roadway Design Manual	http.//onlinemanuals.txdot.gov/txdotmanuals/rdw/index.htm

The survey also asked respondents to specify their agency's goals in having minimum lane width policies and/or lane reduction guidelines. Results from this question showed that improving traffic safety was the top-rated agency goal (92.3%), followed by improving safety for pedestrians and bicycles (69.2%). Meanwhile, increasing active transportation use and reducing construction and maintenance costs were jointly third (i.e., 61.5% apiece). With a share of 53.8%, reducing vehicle speeds was ranked fourth by respondents. Other agency goals like improving multi-mobility, connectivity benefits, stewardship of public funds, maintaining driver expectancies, and roadside activity were the least prioritized expectations (i.e., 7.7% each).

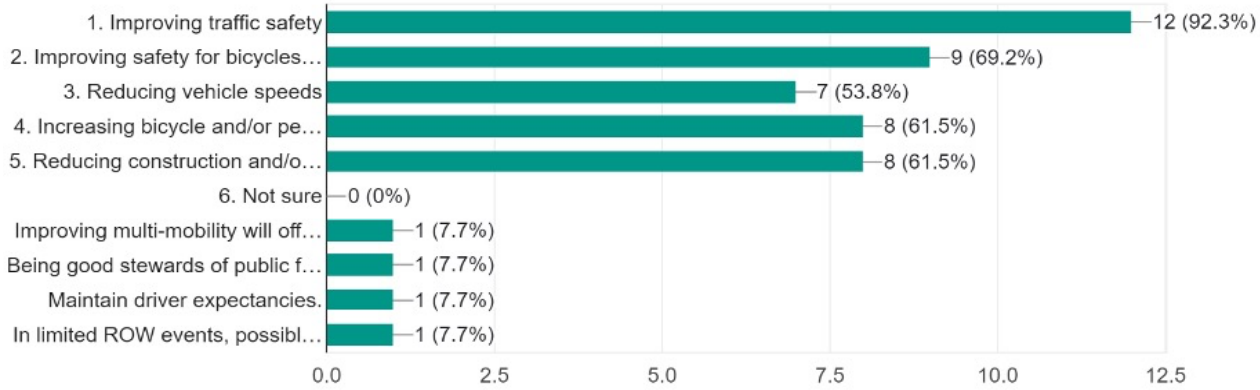


Figure 5-1 Prioritized Agency Goals and Expectations in Having Lane Width Policies & Standards

All (*100%*) respondents indicated that they have a design exception process where lane width reductions can be proposed, reviewed, and approved. The specific conditions (e.g., speed, traffic volume, functional class, zoning) that enable reduced lane widths to be considered by the respondents included but are not limited to:

- "Roadway classification, ADT, speed"
- "Reduced lane widths are considered on a project by project basis, and are not based on specific conditions"

- “We review based on trying to achieve a balance of economics and project needs”
- “Typically urban settings, many times where some reduced lanes already exist”
- “None, however, Caltrans is evaluating and developing guidance to allow for narrower lane widths based on the context type”
- “In addition to above-listed conditions, public transportation (bus route), turn movements, on-street parking, access management”
- “We view these as context-sensitive issues unique to each project. Some of the things considered are funding, impacts on property, impacts to the environment, speed, traffic volume, and modal accommodation”
- “Background information and design guidance for selecting lane widths are identified on pages 25-26 of our PBPD Process and Design Guidance document”
- “A few conditions (to name a few) that enable reduced lane widths to be considered are design speed, anticipated vehicular traffic, safety, terrain along with other conditions found in section 1100 of our preconstruction manual as well as in the AASHTO Green Book”
- “Safety, capacity, operational considerations, and needs”
- “Urban or rural context, traffic volume, speed, and functional classification”
- “Mainly good engineering judgment and also past performance on similar roadway types”
- “The RDM allows the reduction of lane widths to add a TWLTL, add bicycle facilities, and reduce the crossing width for pedestrians at intersections. Additional circumstances may include ROW limitations, area type or context, and functional classification”

In terms of authority to approve lane width design exceptions, the responses from the AASHTO committee members are provided in Table 5-2 .

Table 5-2 Responsible Entity for Approving Lane Width Reduction

AASHTO Committee Member	***Response***
Michigan DOT	Engineer of Road Design
Ohio DOT	The ODOT Roadway Engineering Administrator approves lane width design exceptions. The Designer will submit the exception to one of our Central Office Geometric Subject Matter Experts for review. If the Geometric Subject Matter Expert finds the exception valid, they will forward it to the Roadway Engineering Administrator for approval. We have a website for submitting/reviewing/approving design exceptions.
Alabama DOT	The designer can make the recommendation. A design variance will need to be developed for any narrower width roads, and it will be signed by the Designer, Region Engineer, State Design Engineer & Chief Engineer.
Maine DOT	Maine DOT Engineering Council has the authority to review and approve these requests.

AASHTO Committee Member	***Response***
California DOT	Design exceptions are documented in a Design Standard Decision Document (DSDD). For lane widths standards, approval authority is delegated to the District Directors for all highway classifications except for interstate freeways that the Headquarters Project Delivery Coordinators approve.
Tennessee DOT	The Director of the Design Division
Washington State DOT	Assistant State Design Engineers or delegates, depending on route and project type.
Minnesota DOT	N/A
Alaska DOT	The regional preconstruction engineer approves or rejects the proposed design exception request. If approved, an informational copy of all approved design exceptions must be furnished to FHWA. Now, for high-profile projects, FHWA must concur with design exceptions.
Arizona DOT	The Asst. State Engineer - Roadway Engineering Group approves Design Exceptions and Variances associated with AASHTO's controlling criteria and ADOT's Design Standards. This includes lane width reduction. Currently, FHWA provides final approval of Design Exceptions associated with the Controlling Criteria.
Montana DOT	Lane width exceptions are documented and approved by either the State Traffic and Safety Engineer or the Highways Engineer depending on the nature of the project. Urban exceptions are a "variance" documented in a Scope of Work report. Rural or high-speed exceptions are design exceptions. Design Exceptions are a more robust analysis and justification goes in a standalone report.
Kentucky DOT	The Project Manager makes a recommendation, and the Director makes final approval of the highway design.
Texas DOT	Project types requiring design exceptions to be submitted to the FHWA are first reviewed by TxDOT Design Division and then transmitted to FHWA for approval. The respective TxDOT District approves all other project design exceptions.

Survey results revealed that a little over half (*i.e., 53.8%*) of the responding AASHTO committee members were aware of completed or ongoing lane reduction projects implemented in their jurisdictions. 30.8% of respondents reported that no lane reduction projects had been completed or are ongoing in their jurisdictions. The remaining 15.4% of respondents were unsure whether there were any completed or yet-to-be implemented lane reduction projects in their jurisdictions.

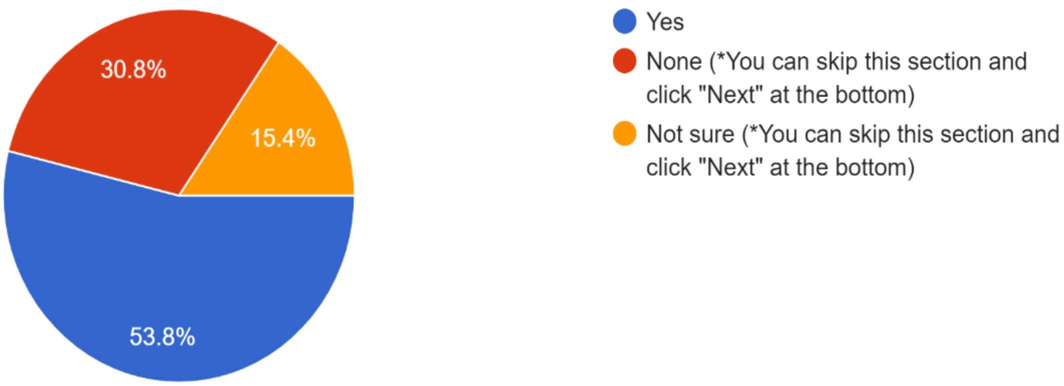


Figure 5-2 DOTs Knowledge of Completed/Ongoing Lane Width Reduction Projects in Their Jurisdiction

Explaining further, respondents were requested to provide an exemplary lane reduction project in their jurisdiction with details of their name, location, web sources, and references. Responses from the survey results are provided in Table 5-3 .

Table 5-3 Details of Exemplary Lane Width Reduction Projects in DOTs Jurisdiction

AASHTO Committee Member	***Response***
Michigan DOT	Currently under development, so there are no finalized documents; however, reducing lane widths to accommodate wider sidewalks for pedestrians.
Ohio DOT	IR-71 SB north of Columbus - Lane widths were reduced on the interstate to add an additional lane to increase capacity. Please email me for additional details/reports.
Alabama DOT	N/A
Maine DOT	N/A
California DOT	N/A
Tennessee DOT	There are many, in addition to the resurfacing lane reconfiguration or Road Diet requests from locals. Many were reduced from 12 to 11 to accommodate MM. Few reduced to 10'.
Washington State DOT	SR 4 / SKAMOKAWA VIC, TO 0.3 MILES WEST CHIP SEAL
Minnesota DOT	Cases where we utilize narrow through-lanes would include; small-town downtown areas (*particularly those with bike lanes or TWLTLs*), low-speed areas where speed control is a project goal, and high-speed freeway settings where the narrowed lanes allow the inclusion of additional capacity. Narrow lanes were installed on I-94 to address an emergency need for additional capacity. It was found that narrow lanes combined with increased capacity exhibited better crash performance than the previous condition. A low-speed example would be St. James, where

AASHTO Committee Member	***Response***
	narrow lanes were combined with mini-roundabouts and back-in diagonal parking for excellent results (https.//www.youtube.com/watch?v=Elto-q4T5Ag).
Alaska DOT	N/A
Arizona DOT	Conversion of system ramp from one lane to two lanes. This required narrower shoulders and narrower lanes to fit the additional lane within the limits of the existing bridge and bridge barriers—more information upon request.
Montana DOT	N/A
Kentucky DOT	This project is located in Frankfort, KY (Franklin County) - US 60 from Sunset Drive to Laralan Drive, Item 5-526.00
Texas DOT	N/A

The survey additionally investigated the primary objectives for DOTs when considering a lane reduction for a specific site. The results revealed that improving traffic safety and safety for bicycles and pedestrians were the primary objectives, with shares of 66.7% apiece. The next rated primary objective for DOTs when considering a lane reduction was the reduction of construction and maintenance costs (*55.6%*). Meanwhile, reducing vehicle speeds and increasing active transportation usage had equal shares of 44.4% each. Variables like providing context-appropriate widths, reducing congestion and utility costs, limiting traffic impacts, and quick turnaround for project delivery were the least prioritized objectives (*i.e., 11.1% each*).

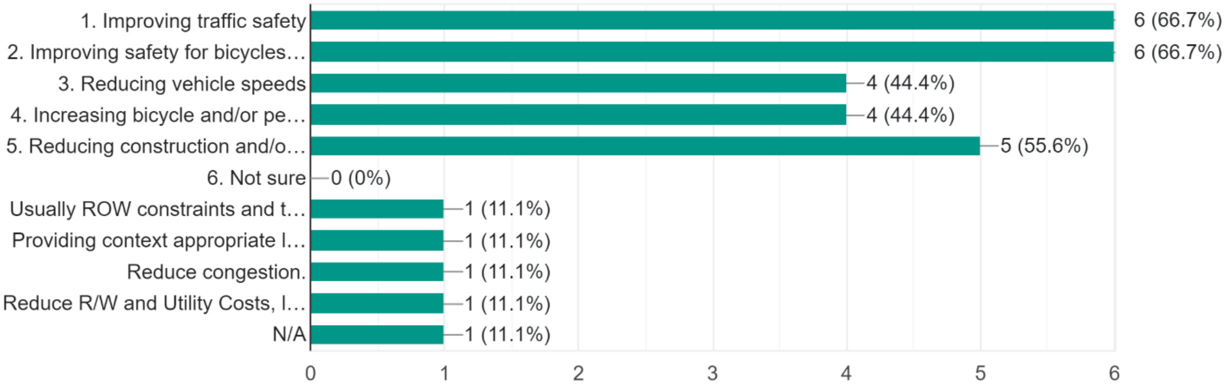


Figure 5-3 DOTs Primary Objectives When Considering Lane Reduction Projects for Specific Sites

Regarding post-implementation impacts, the survey respondents reported that three (3) significant changes were observed or measured. These were changes in traffic safety (*33.3%*), changes in vehicle speeds (*33.3%*), and changes in construction and maintenance costs (*33.3%*).

Other observed or significant measurable changes included bicycle and pedestrian activity changes and reduced congestion (*11.1% each*). Whereas some 11.1% of respondents indicated that no significant changes had been observed yet, others (*11.1%*) maintained that they were unsure or that the impacts were too soon to report.

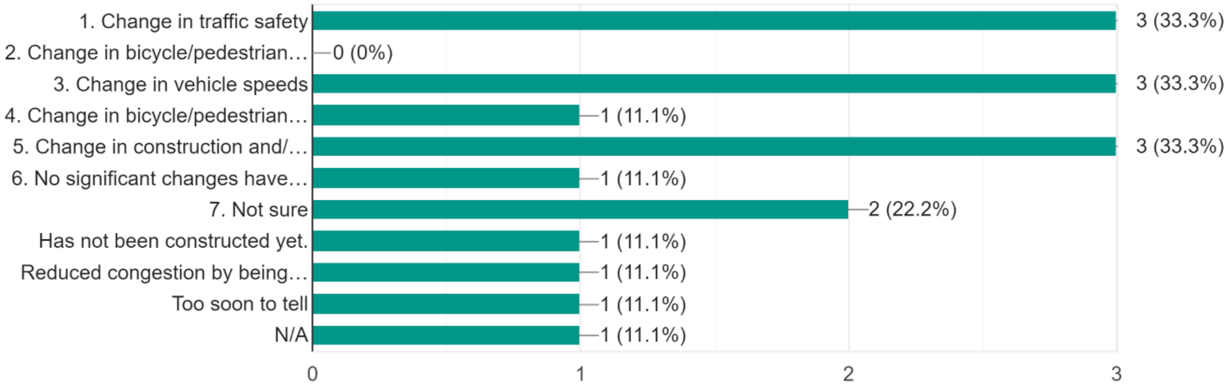


Figure 5-4 DOTs Overall Observed/Measured Changes After Reducing Lane Widths

Concerning the observed/measured safety impacts after reducing lane widths, the majority of respondent DOTs (*i.e., 66.7%*) revealed that they were unsure about the safety impacts. Meanwhile, some 11.1% of respondents indicated that they had observed decreased rates and crash severity. The remaining responses circulated around inadequate data to show impacts, no significant observed changes, and the absence of any lane reduction projects in their jurisdictions.

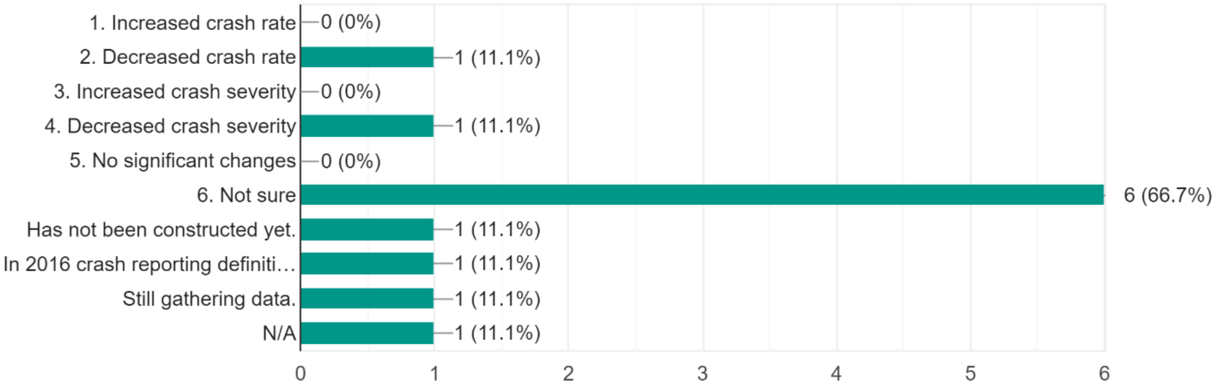


Figure 5-5 DOTs Observed/Measured Safety Changes After Reducing Lane Widths

Regarding the observed/measured changes in vehicle speed after reducing lane widths, half of the survey respondents (*50%*) intimated that they were unsure about the impact, whereas a little over a third of respondent DOTs (*37.5%*) indicated that there had been some observed decreases in vehicle speeds. The remaining 12.5% of DOTs revealed no significant changes either due to non-implementation of any lane-width reduction projects, data availability, too early to tell, or a combination of the above.

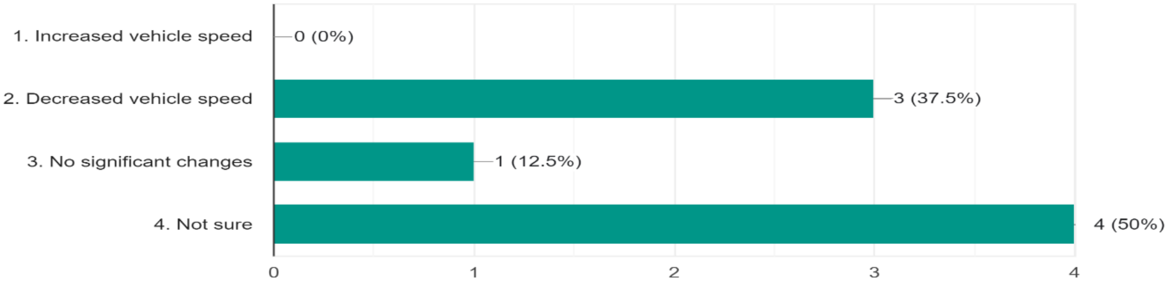


Figure 5-6 DOTs Observed/Measured Vehicle Speed Changes After Reducing Lane Widths

In terms of the observed/measured changes in traffic volume after reducing lane widths, half of the survey respondents (*50%*) indicated that no significant changes or impacts had been observed, whereas a little over a third of respondents (*37.5%*) suggested that they were unsure about any observed changes in traffic volume. Meanwhile, the remaining 12.5% of DOTs indicated that traffic volume had increased after the lane width reduction.

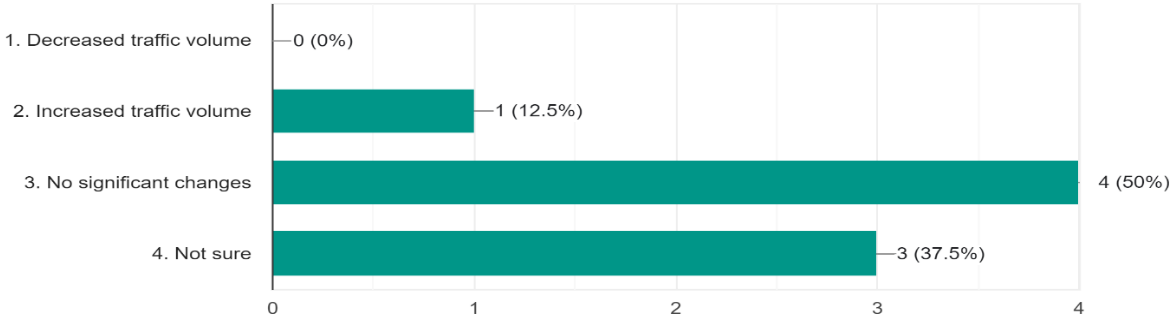


Figure 5-7 DOTs Observed/Measured Traffic Volume or Speed Changes After Reducing Lane Widths

Concerning the observed/measured changes in pedestrian and bicyclist volume after reducing lane widths, over 60% of the survey respondents suggested that they were unsure about the impact. In contrast, some 12.5% of respondent DOTs further indicated that they had not observed any significant changes in pedestrian and bicyclist volumes. Moreover, 25% of respondent DOTs indicated that they had observed or measured an increase in the volumes of pedestrians and bicyclists.

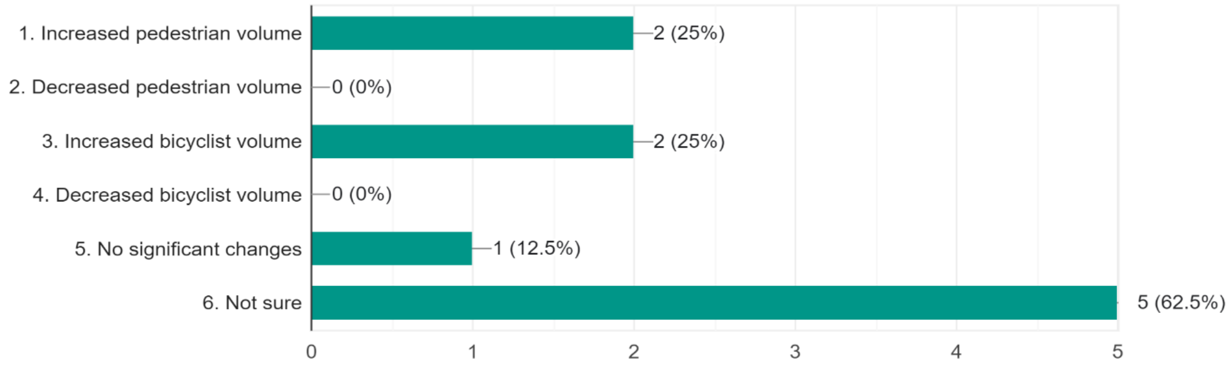


Figure 5-8 DOTs Observed/Measured Pedestrian/Bicyclist Volume Changes After Reducing Lane Widths

Regarding the observed/measured changes in construction and maintenance costs after reducing lane widths, half of the survey respondents (*50%*) were unsure about the impact. In contrast, another half of respondents (*50%*) indicated that there had been some observed decreases in construction and maintenance costs. The remaining 12.5% of DOTs suggested no observed or measured significant changes.

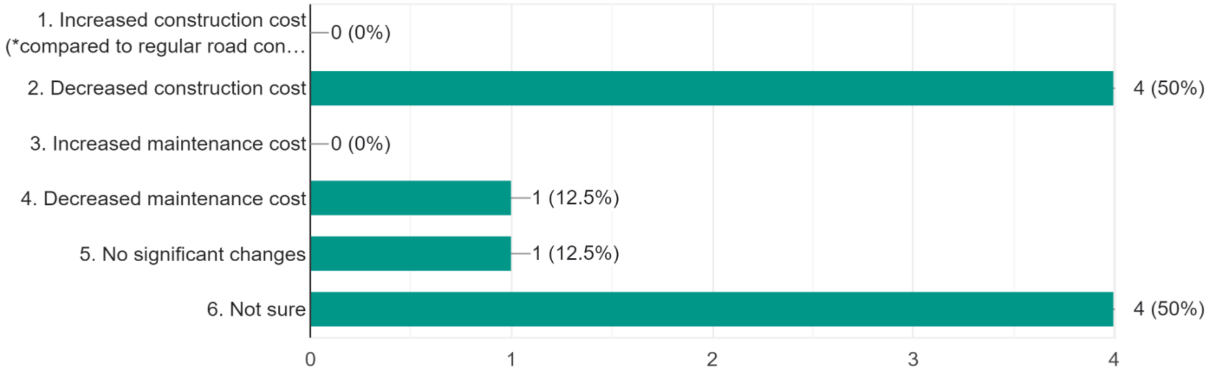


Figure 5-9 DOTs Observed/Measured Construction/Maintenance Cost Changes After Reducing Lane Widths

The survey questionnaire further asked AASHTO committee members about the physical changes implemented (*i.e., cross-sectional road design*) while reducing lane widths. The results from the survey showed that pedestrian refuge islands were the top implemented (*i.e., 57.1%*) physical changes to the road cross-sectional designs. The expansion of pedestrian sidewalks and multi-modal transportation infrastructure closely followed with 42.9% apiece. The next significant physical changes implemented were on-street parking and traffic calming measures with shares of 28.6% each. Other observed physical changes resulting from lane width reduction were street trees, landscaping, rapid flashing beacons, and commercial entrance improvements.

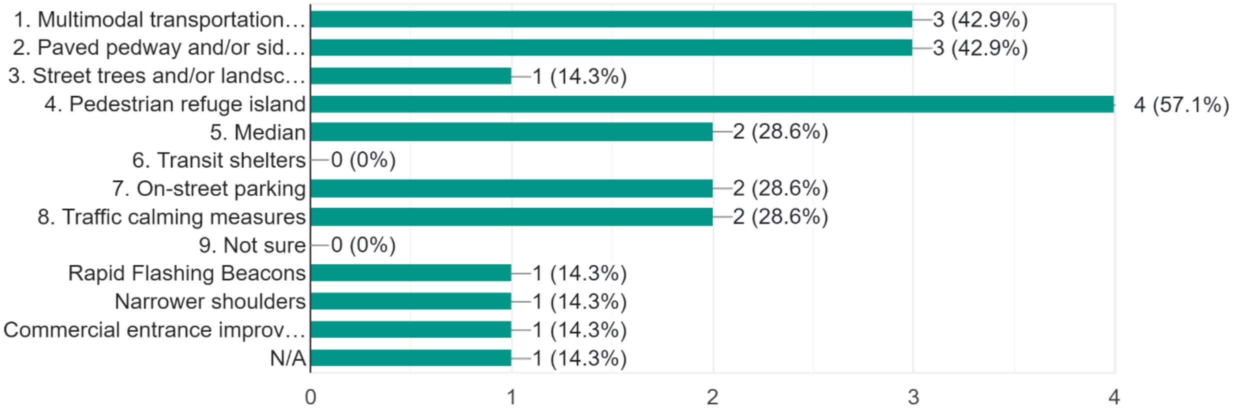


Figure 5-10 DOTs Observed Physical Changes in Road Cross-Section Design After Reducing Lane Widths

Considering these cumulatively measured and observed changes, the survey probed further to assess the overall expected impacts of reducing lane widths. The responses included:

- “Improving overall safety and accommodating ADA sidewalk width”
- “Reducing lane widths to improve multi-modal accommodation and to reduce cost. In urban areas, 11' is common for freeway lane width to increase capacity and minimize cost”
- “They allow increased widths on adjacent pedestrian facilities and can reduce congestion-related crashes by being able to add lanes at a reduced cost. We do not recommend reduced lane widths to reduce speeds - as this alone is not a proven countermeasure to reduce speeds. Studies have not consistently shown a speed reduction - and sometimes an increase in speed”
- “We believe it is a viable option in some urban settings”
- “Accommodating truck or bus (lateral offset), turn radius, over tracks, vehicles violating bike lanes”
- “Our expectations surrounding reducing lane widths fall in line with the expectations identified in NCHRP 783, in that we can expect similar or improved safety performance while providing elements that improve the safety and functionality for all users, not just motor vehicles”
- “Impact on capacity and speed. Evaluation of operational and safety impacts must be considered”
- “A balance between cost of project and benefit received, provide an effective project that meets the scope of the project”

Concerning the possibility of other elements of the lane-width reduction project that might have contributed to a decrease in crashes, speed, traffic, and pedestrian volumes besides lane width reduction, the respondent DOTs made references to the following:

- “Refuge islands for pedestrians”
- “A location where only lane width reduction is proposed without reducing speed limit should be investigated for ADT (*many MM documents limit ADT 6000-10000 range*) however existing major collector or arterial capacity easily pass well above those numbers”
- “Speed feedback signs, rapid flashing beacons”
- “We have found that manipulating one design element is not sufficient to provide a design that is appropriate for the context or to adjust driver/user behavior. We believe, and our efforts have demonstrated, that a holistic approach is necessary, using all available context cues and design elements, to provide a design that matches the context of the roadway segment”
- “Signage and striping enhancements”
- “Right-in Right-out change in access and improved entrance geometrics (added a right-turn lane and improved entrance grade)”

It was worth noting that all the respondent AASHTO Committee Members (100%) showed interest in the results of this research – expecting to see the final results and report in the future.

6.0 QUANTITATIVE ANALYSIS OF LANE WIDTH VS. VEHICLE SPEED AND CRASH FREQUENCY FOR UDOT ARTERIALS

As we mentioned in the literature review, researchers have produced mixed findings on the effect of lane widths on roadway speed and safety. Several studies found that narrower lanes increase road safety (reduce crash frequency) as compared to wider lanes (Milton and Manning, 1998; Strathman et al., 2001; Noland, 2003; Hauer et al., 2004; Potts et al., 2007.) Milton and Manning (1998) observed narrower lanes (less than 11.5 feet) with lower speeds reduce crash frequency. Noland (2003) states that having lane widths of 12 feet or more for arterials increase total fatalities and injuries. Therefore, he argued that lane widths over 11 feet do not contribute to road safety. Potts et al. (2007) also found no evidence suggesting that lanes narrower than 12 feet increase crash frequency and hence they supported AASHTO Green Book's policy of providing substantial flexibility for using narrower lanes on urban arterials. However, some researchers have found opposite results showing that wider lanes increase road safety (Hadi et al., 1995; Dumbaugh, 2006; Yanmaz-Tuzel and Ozbey, 2010).

Our case studies of five leading state DOTs produced no before-and-after studies of lane narrowing with respect to speed or safety. Nor did our survey of AASHTO Committee members. Thus, these two project tasks added no empirical evidence to our literature review. We have become convinced that additional research is required to address the costs and benefits of narrower lanes.

Therefore, as the last task of the current project, we have conducted such a study following best research practices and using data for state arterials in Utah.

6.1. Study Sites

In this report, we studied UDOT arterials in urban and rural areas of the state. According to the Highway Safety Manual (AASHTO, 2018), an area is considered urban if 50,000 or more people live in the area. While inconsistent with the U.S. Census, this has become our definition of urban (the census would define an area of 50,000 population as urbanized and would classify small towns as urban).

Table 6-1 Descriptive Statistics of Roadway Study Sections

	Count	Ratio	Mean	Median	Min.	Max.	S.D.
All	1883	100%					
Average Length (Miles)			2.02	0.86	0.045	49.28	4.11
Average Lane Width (ft)			11.97	12	9.5	21.11	0.76
Urban Area	1189	63.10%					
Average Length (Miles)			0.79	0.63	0.05	5.13	0.56
Average Lane Width (ft)			11.90	11.98	9.5	21.11	0.75
Rural Area	531	28.20%					
Average Length (Miles)			5.11	2.69	0.08	49.28	6.77
Average Lane Width (ft)			12.05	12	10.17	17.04	0.68
Small Town	163	8.70%					
Average Length (Miles)			0.93	0.65	0.08	7.01	0.83
Average Lane Width (ft)			12.19	12	10.78	17.56	0.99

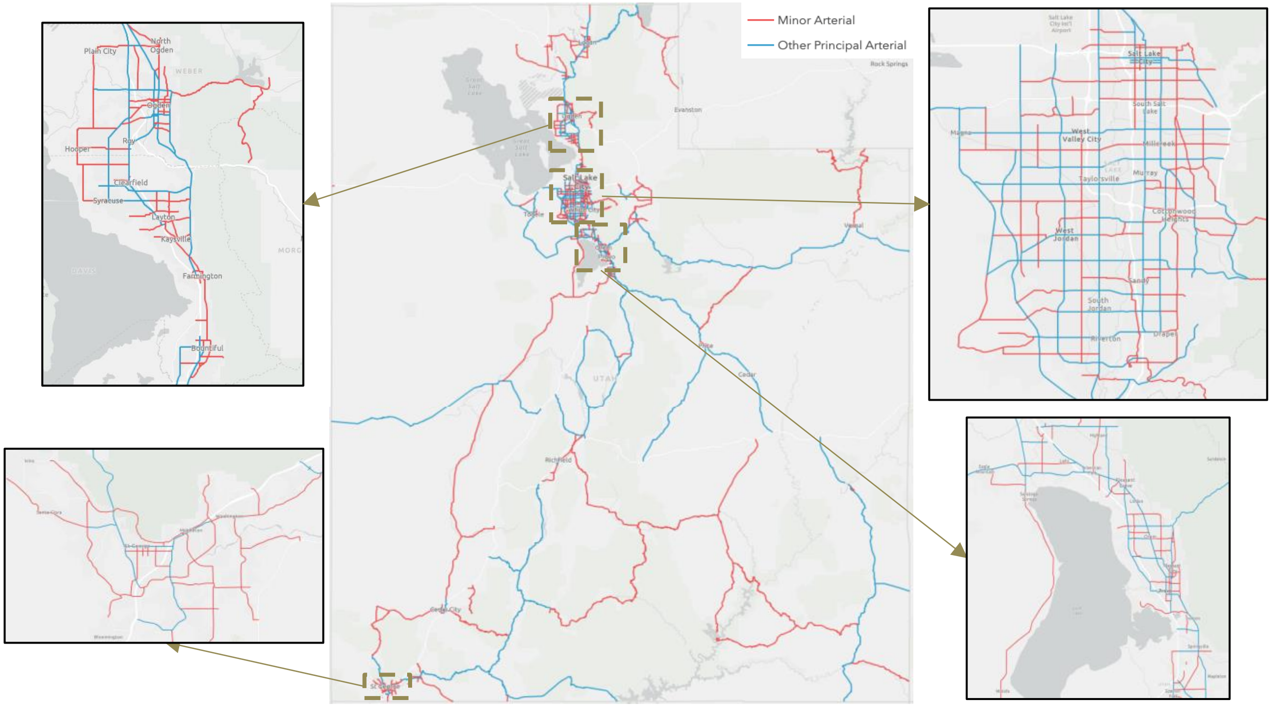


Figure 6-1 Geographic Map of Study Sections

6.2. Units of Analysis

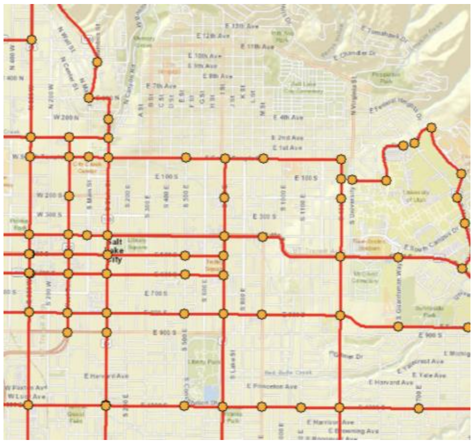
The literature often uses two definitions of roadway units for the purposes of analysis. First, studies use segments from intersection to intersection as the units of analysis (Liu et al., 2018; Wood et al., 2015; Potts et al., 2007; AASHTO, 2010). According to the Highway Safety Manual (AASHTO, 2010), midblock segments "begin at the center of an intersection and end at either the center of the next intersection or where there is a change from one homogeneous roadway segment to another homogeneous segment." The segments need to be homogeneous with respect to annual average daily traffic volume and key roadway design characteristics (e.g., number of through lanes, presence/type of median, presence/type of on-street parking). This manual suggests limiting the segment length to a minimum of 0.10 mi. to minimize calculation efforts without affecting results.

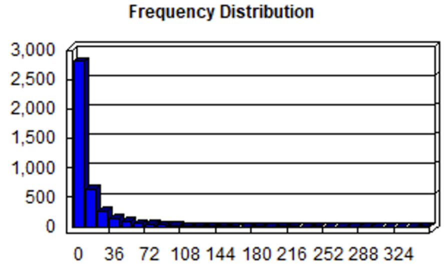
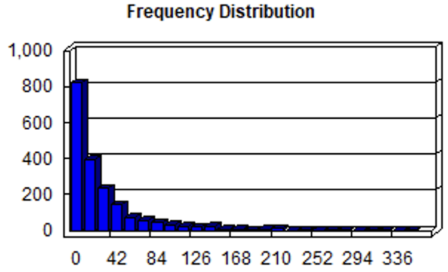
Another set of the literature employs longer sections of roads for analysis, which often include multiple segments (Manuel et al., 2014; Park et al., 2016; Chen et al., 2020; TRB, 2010). The Highway Capacity Manual (NASEM and TRB, 2022) defines an urban street facility as "a length of roadway composed of contiguous urban street segments and is typically functionally classified as an urban arterial or collector street." According to this manual, an urban street facility typically has a length of 1 mile or more in downtown areas and 2 miles or more in other areas with no significant change in one or more facility cross-sectional features (e.g., number of through lanes, shoulder width, curb presence), annual average daily traffic volume, roadside development density and type, and vehicle speed.

While both segmentation methods are expected to produce units with a certain level of homogeneous characteristics, we found differences that may affect the models' statistical power and practical significance. Table 6-2 shows the segmentation results for UDOT arterials using the two methods explained above. Looking at Method 1, as midblock segments with a shorter length likely have uniform design characteristics within the segments, one observation is expected per unit. With a short data collection time for one unit, this approach allows examining a relatively larger sample (e.g., 700 units for urban areas and 300 units for rural areas) with little possibility of compromising the homogeneity of the roadway design of a unit. However, as shown in the table, the use of shorter units results in more zero-crash cases, potentially including false zeros occurring due to the short length of the units rather than due to the roadway design features.

On the other hand, Method 2, based on road sections, can overcome this issue by producing longer units and a smaller number of zero-crash cases. However, as road sections are made up of multiple segments, possibly with different road designs, more observations may be required per unit. Further, with the prolonged data collection time, the sample analyzed will be smaller than the first method, potentially reducing its statistical power.

Table 6-2 Analysis of Units and Characteristics

Analysis units	**Method 1. midblock segments**	**Method 2. sections of road**
Unit characteristics	- Total number of units in Utah. 4,125 - mean 0.9 mi. - range 0.1-35mi. 	- Total number of units in Utah. 1,869 - mean 2.0 mi. - range 0.1-49.3 mi. 
Data collection time per sample	- Relatively shorter	- Relatively longer to examine multiple midblock segments
Number of crashes (*based on 5-yr of data)	- zero crash samples. 16% (644 out of 4,125) - mean 14 - range 0-355	- zero crash samples. 5% (85 out of 1,869) - mean 31 - range 0-355

Analysis units	Method 1. midblock segments	Method 2. sections of road
		
References	Liu et al., 2018; Wood et al., 2015; Pott et al., 2007; AASHTO (2010) Highway Safety Manual	Manuel et al., 2014; Park et al., 2016; Chen et al., 2016; NASEM and TRB, 2022)

In this study, we decided to use sections of roadways as our units of analysis. Although identifying homogeneous roadway sections required more time and reduced our sample size, it produced fewer zero-crash cases. Furthermore, road sections covering multiple intersections are more analogous to sites for local roadway improvement projects and often correspond to units for which AADT is available from UDOT. With sections rather than segments, we minimize the problem of dependence of adjacent segments, which violates the independent assumption of regression analysis.

6.3. Data Collection

While secondary data are available from UDOT for some road design variables, many other variables require manual observation. Thus, we utilized Google satellite imagery to fill the gaps in the database. We designed the following procedure to ensure the reliability of the data collected by multiple people and identify homogeneous roadway sections (Figure 6.2).

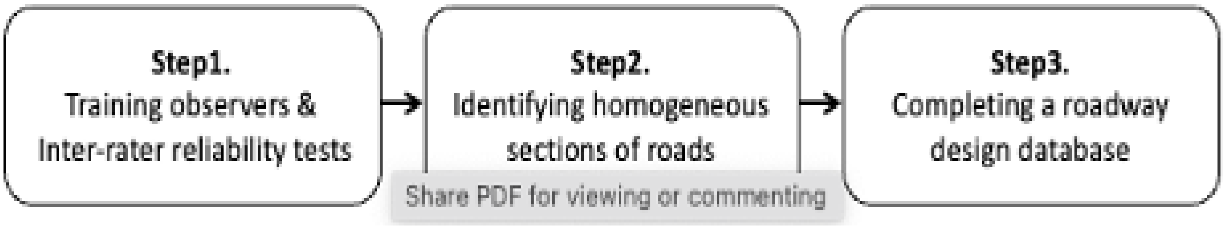


Figure 6-2 Roadway Design Variable Protocol

Step 1. Training Observers & Inter-Rater Reliability Tests

Different research team members collected data for different roadway sections, raising questions of consistency and reliability. In Step 1, we chose Cronbach's alpha tests, a statistical technique widely accepted in assessing the internal consistency or reliability between measurements or ratings. Cronbach's alpha values range on a scale from zero to one, where a higher value indicates a strong resemblance or internal consistency among the observations. A lower value (near 0) implies the absence of consistency among the ratings (Bujang et al., 2018, Leontitsis & Pagge, 2007, and Gliem & Gliem, 2003). According to the sample size table provided by Bujang et al. (2018) for varying effect size, a Cronbach's alpha value of 0.7 or more is considered an acceptable result showing high consistency.

Among the total sample pool, 21 roadway sections were randomly selected, and five researchers from the Metropolitan Research Center (MRC) collected data for these same samples on 18 variables separately to check to what degree their ratings match following the guidelines of Cronbach's alpha. After two weeks of in-depth data collection for those 21 cases using Google Satellite Imagery and the Iteris Clear Guide Website, the results of the statistical model showed Cronbach's alpha value of 0.7 and higher for all 18 variables (Table 6-3), suggesting high consistency and reliability among the ratings. Hence from this pilot test, raters could confidently proceed to collect data for the entire sample independently and separately following a data collection protocol.

Table 6-3 Cronbach's Alpha Values for Inter-Rater Reliability Tests

Variable	Test Name	Value
Lane width	Cronbach's alpha	0.910
Number of lanes	Cronbach's alpha	0.972
Median width	Cronbach's alpha	0.973
Median type	Cronbach's alpha	0.945
Shoulder width	Cronbach's alpha	0.809
Shoulder type	Cronbach's alpha	0.882
Sidewalk	Cronbach's alpha	0.981
Bike lane	Cronbach's alpha	0.964

Variable	Test Name	Value
Bus stop	Cronbach's alpha	0.956
Parking lane	Cronbach's alpha	0.910
Parked cars	Cronbach's alpha	0.979
Curvature	Cronbach's alpha	0.884
Sky ahead	Cronbach's alpha	0.709
Objects	Cronbach's alpha	0.891
Intersections	Cronbach's alpha	0.920
Speed limit	Cronbach's alpha	0.881

Step 2. Identifying Homogeneous Sections of Roadway

In the following stage, researchers were asked to identify the homogeneity (uniformity) of sections of roadway. For this, each data collector was assigned a sample of approximately 380 roadways from a total sample pool of 1,883 roadway sections of urban and rural roads in the state of Utah. The homogeneity of the road sections was identified by examining the cross-sectional roadway designs through Google Satellite Imagery and Clear Guide Website based on seven criteria shown in Table 6-4. The results were recorded in the form of a binary variable, 1 meaning inclusion and 0 meaning exclusion of the case for further data collection.

Table 6-4 Observation Protocol for Identifying Homogeneous (Uniform) Roadway Sections

Criteria	Observation Protocol
Number of lanes	Observed the through lanes in both directions. Ignored flush medians and turning lanes near intersections. If any change (e.g., 4 lanes to 6 lanes) is observed, it is recorded as 0. If uniform, it is recorded as 1.
Posted speed limit	Measured the speed limit from the ClearGuide website. If any change is observed (e.g., 50 mph to 55 mph), it is recorded as 0. If uniform, it is recorded as 1.

Criteria	Observation Protocol
Lane width	Measured the lane width at multiple random points along a section. If any difference is over 1 ft (e.g., widened road at a sharp curve), it is recorded as 0. If uniform, it is recorded as 1.
Median width/type	If any significant change in the median width (e.g., 12 ft to 3 ft) or median type (e.g., traversable to non-traversable), it is recorded as 0. If uniform, it is recorded as 1.
Shoulder width/type	If any significant change in the shoulder width (e.g., 12 ft to 3 ft) or shoulder type (e.g., present in one direction to absent), it is recorded as 0. If uniform, it is recorded as 1.
Sidewalk	If any significant change in the presence of sidewalks (e.g., present to absent), it is recorded as 0. If uniform, it is recorded as 1.
Bike lane	If any significant change in the presence of bike lanes (e.g., present to absent), it is recorded as 0. If uniform, it is recorded as 1.

Step 3. Collecting Roadway Data

In the last stage, a detailed database of approximately 700 homogeneous (uniform) roadway sections was created, compiling data for 18 variables collected from Google Satellite Imagery and Clear Guide Website over a period of six weeks by a team of five research assistants. To collect information on lane width, median width, shoulder width, and Euclidean distance between the start and end points of the roadway section, we used the measurement tool in Google Earth Pro software. We collected measurements at three reference points and noted the average value for lane width, median width, and shoulder width. Next, from the aerial view feature of Google Earth Pro, we collected information on the number of lanes, median and shoulder types, the presence of sidewalks, bike lanes, intersections, and parking lanes.

We closely examined the satellite images in the areal views and noted each of the variables; minor deviations in the roadway sections were overlooked. Next, we searched for bus stops in the search panel of the software to determine if there were any bus stops in our roadway sections.

Lastly, we used the Street View feature in Google Earth Pro to assess the roadway environment and estimate the sky ahead and nearby objects variables. If an average of less than 50 percent of the view from the horizon upward was blocked by trees, buildings, and other objects, the proportion sky ahead dummy variable assumed a value of 1. Otherwise, it assumed a value of 0. The objects variable was measured by the percentage of the section with objects, including buildings, trees, and bus shelters, within 50 feet of the pavement edge. If more than 50 percent of the section was proximate to objects, the binary variable equaled 1; otherwise, it was 0.

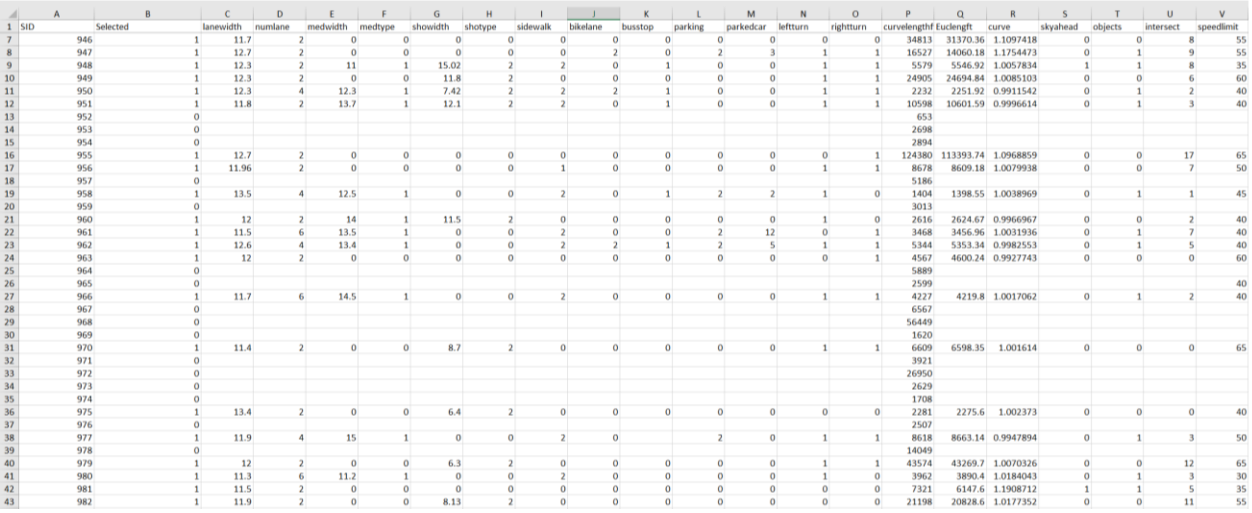
Apart from Google Earth Pro, we also used ArcGIS software to create shape files of our samples and to collect the total length of each roadway section. By dividing the total length by the Euclidean distance, we obtained a measure of curvature for each roadway section. Moreover, we used the Iteris Clear Guide website and UDOT’s speed limit shapefile to find speed limit data for each roadway section.

Furthermore, we measured the block length, which is the average distance between two consecutive intersections, or in other words, the frequency of intersections. The block length was calculated based on the number of intersections and the segment length using the equation below. We added 1 to the denominator to account for the beginning and end of each section.

$$Block\ Length = \frac{Segment\ Length}{Intersections + 1}$$

Moreover, we estimated the Annual Average Daily Traffic (AADT) per lane to determine the average traffic flow in each lane, which may be correlated with speed. This variable was included in our dataset to reflect the impact of normalized traffic in our modeling. We adopted a similar approach for analyzing crash data. Since the length of each section varies, we adjusted the crash and injury crash counts for each section accordingly on a per mile basis. However, we rounded the crash rates to the nearest integer to ensure that the crash records remained as count values and therefore were analyzable with count regression models, commonly used in crash analyses. Additionally, we considered the impact of on-street parking and parked cars on safety and traffic speed by normalizing the number of parked cars based on the length of the section.

We collected all the information for each roadway section and compiled them in one Excel spreadsheet creating a database to support our modeling process.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	SID	Selected	lanewidth	numlane	medwidth	medtype	showidth	shotype	sidewalk	bikelane	busstop	parking	parkedcar	leftturn	rightturn	curvelengthf	Euclengft	curve	skyahead	objects	intersect	speedlimit
7	946	1	11.7	2	0	0	0	0	0	0	0	0	0	0	0	34813	31370.36	1.1097418	0	0	8	55
8	947	1	12.7	2	0	0	0	0	0	2	0	2	3	1	1	16527	14060.18	1.1754473	0	1	9	55
9	948	1	12.3	2	11	1	15.02	2	2	0	1	0	0	1	1	5579	5546.92	1.0057834	1	1	8	35
10	949	1	12.3	2	0	0	11.8	2	0	0	0	0	0	1	1	24905	24694.84	1.0085103	0	0	6	60
11	950	1	12.3	4	12.3	1	7.42	2	2	2	1	0	0	1	1	2232	2251.92	0.9911542	0	1	2	40
12	951	1	11.8	2	13.7	1	12.1	2	2	0	1	0	0	1	1	10598	10601.59	0.9996614	0	1	3	40
13	952	0														653						
14	953	0														2698						
15	954	0														2894						
16	955	1	12.7	2	0	0	0	0	0	0	0	0	0	0	1	124380	113393.74	1.0968859	0	0	17	65
17	956	1	11.96	2	0	0	0	0	1	0	0	0	0	1	1	8678	8609.18	1.0079938	0	0	7	50
18	957	0														5186						
19	958	1	13.5	4	12.5	1	0	0	2	0	1	2	2	1	0	1404	1398.55	1.0038969	0	1	1	45
20	959	0														3013						
21	960	1	12	2	14	1	11.5	2	0	0	0	0	0	1	0	2616	2624.67	0.9966967	0	0	2	40
22	961	1	11.5	6	13.5	1	0	0	2	0	0	2	12	0	1	3468	3456.96	1.0031936	0	1	7	40
23	962	1	12.6	4	13.4	1	0	0	2	2	1	2	5	1	1	5344	5353.34	0.9982553	0	1	5	40
24	963	1	12	2	0	0	0	0	0	0	0	0	0	0	1	4567	4600.24	0.9927743	0	0	0	60
25	964	0														5889						
26	965	0														2599						40
27	966	1	11.7	6	14.5	1	0	0	2	0	0	0	0	1	1	4227	4219.8	1.0017062	0	1	2	40
28	967	0														6567						
29	968	0														56449						
30	969	0														1620						
31	970	1	11.4	2	0	0	8.7	2	0	0	0	0	0	1	1	6609	6598.35	1.001614	0	0	0	65
32	971	0														3921						
33	972	0														26950						
34	973	0														2629						
35	974	0														1708						
36	975	1	13.4	2	0	0	6.4	2	0	0	0	0	0	0	0	2281	2275.6	1.002373	0	0	0	40
37	976	0														2507						
38	977	1	11.9	4	15	1	0	0	2	0		2	0	1	1	8618	8663.14	0.9947894	0	1	3	50
39	978	0														14049						
40	979	1	12	2	0	0	6.3	2	0	0	0	0	0	1	1	43574	43269.7	1.0070326	0	0	12	65
41	980	1	11.3	6	11.2	1	0	0	2	0	0	0	0	1	0	3962	3890.4	1.0184043	0	1	3	30
42	981	1	11.5	2	0	0	0	0	0	0	0	0	0	0	0	7321	6147.6	1.1908712	1	1	5	35
43	982	1	11.9	2	0	0	8.13	2	0	0	0	0	0	0	0	21198	20828.6	1.0177352	0	0	11	55

Figure 6-3 Snippet of Collected Data in Excel

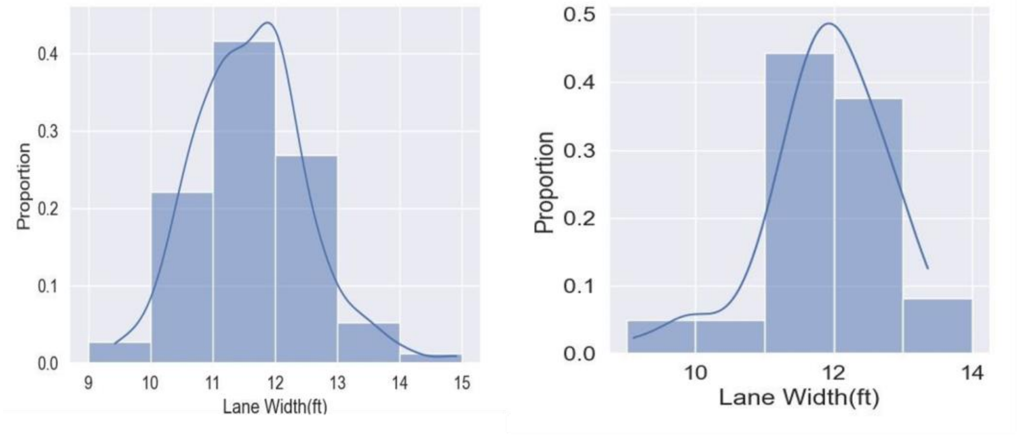
The width of a roadway's lane is often posited to have an impact on both the safety and speed of a given section. However, studies, experts, and practical cases have produced incomplete and conflicting results regarding the relationship between lane width, speed, and safety (see Literature Review). In an effort to better understand this relationship, our analysis focused on identifying a numerical relationship between lane width, speed, and crashes, taking into account a variety of roadway design and other variables. We collected data on these variables for 829 homogeneous (uniform) sections, using traffic volume, speed, and crash data for 2021. Specifically, we sourced speed data from StreetLight, which recorded the daily 50th percentile speed, the 85th percentile speed, and the 95th percentile speed. Additionally, we obtained crash data from the Utah Department of Public Safety (UDPS), focusing exclusively on non-intersection crashes and including all crash records, injury crashes, and fatal crashes that occurred in 2021.

Our team selected StreetLight data for their ability to provide data we required for this study. StreetLight data has been a proven source for data on transportation behaviors over a decade and has been used by DOTs, MPOs, and more across North America. StreetLight data has been validated by multiple third parties including government agencies such as FHWA and other academic institutions including Texas A&M.

One of the challenges encountered during the collection of the dataset was the presence of roadways with lane widths exceeding 14 feet. Upon careful review, it was determined that this issue arose in the absence of striping that separated on-street parking from the road passageway. Consequently, it was decided to exclude these sections from our database. This change was necessary because an unclear definition of the roadway for drivers could impact their driving behavior and, consequently, affect the quantitative analysis results. Following the removal of problematic sections and preprocessing the data for errors and inconsistencies, a total of 389 sections were included in the dataset. To better reflect the road classification in our modeling, we divided the data into urban and rural databases. Of the 389 sections, 325 were located in urban areas, while 64 were situated in rural areas.

Another challenge was the presence of potentially unreliable speed data. Based on StreetLight data, five of the urban roadway sections had median 24-hour speeds of less than 10 mph. Speeds that low seem highly unlikely over a 24-hour period, even on roads with traffic control devices (traffic signals and stop signs). Even if correct, outliers like these could bias results (have a disproportionate impact on regression coefficients). Five were dropped from the urban sample, leaving us with 320 urban sections with median speeds above 10 mph. Three were dropped from the rural sample. Parenthetically, the StreetLight values seem generally reasonable. The simple correlation coefficient between the posted speed limit and the 85th percentile speed, upon which the speed limit is generally based, is 0.701 for urban sections, a degree of correlation we would expect to find if the StreetLight values are valid and reliable. For rural sections, the simple correlation coefficient is 0.779.

The independent variable of primary interest is lane width. As shown in the accompanying figures, the most common roadway width in Utah is 11 to less than 12 feet, followed by those with a width of 12 to less than 13 feet.



(a) (b)

Figure 6-4 Lane Width Distribution of (a) Urban and (b) Rural Sections in the Collected Database

6.4. *Descriptive Statistics*

To gain deeper insights into the database, we generated descriptive statistics in Table 6-5 and 6-6. Apart from the collected data, we added various dummy variables to the dataset to aid in modeling. These assume a value of 1 if present, 0 if absent. We also included and tested the natural logarithm of lane width, hypothesizing that the average speed may be nonlinearly related to these variables.

Table 6-5 Statistical Distribution of Collected Data for Arterial Sections in Urban Areas

Variable	***Mean***	***STD***	***Min***	***25%***	***50%***	***75%***	***Max***
Length (miles)	0.57	0.29	0.13	0.32	0.51	0.80	1.51
Lane Width (ft)	11.62	0.90	9.43	11.01	11.63	12.11	14.91
Lane ≥ 12 ft (dummy)	0.34	0.47	0.0	0.0	0.0	1.0	1.0
Ln (Lane Width)	2.45	0.08	2.24	2.40	2.45	2.49	2.70
Num. Lanes	3.96	1.38	2.0	4.0	4.0	4.0	8.0
Median (dummy)	0.80	0.40	0.0	1.0	1.0	1.0	1.0
Nontraversable Median (dummy)	0.19	0.40	0.0	0.0	0.0	0.0	1.0
Median Width (ft)	10.86	7.02	0.00	8.97	12.30	14.07	41.73

Variable	***Mean***	***STD***	***Min***	***25%***	***50%***	***75%***	***Max***
Shoulder (dummy)	0.68	0.47	0.0	0.0	1.0	1.0	1.0
Shoulder Width (ft)	6.43	5.40	0.00	0.00	6.71	10.61	31.62
Sidewalk (dummy)	0.93	0.26	0.0	1.0	1.0	1.0	1.0
Bike Lane (dummy)	0.19	0.39	0.0	0.0	0.0	0.0	1.0
Bus Stop (dummy)	0.60	0.49	0.0	0.0	1.0	1.0	1.0
Parking Lane (dummy)	0.03	0.18	0.0	0.0	0.0	0.0	1.0
Num. Parked Cars	6.04	15.68	0.00	0.00	0.00	4.25	169.00
Parked Cars (/Mile)	12.84	33.11	0.00	0.00	0.00	9.76	362.02
Curve Length (ft)	3041.70	1548.27	699.61	1705.15	2682.23	4334.57	7995.77
Euclidean Length (ft)	3017.45	1528.49	700.83	1639.08	2677.24	4268.39	8036.47
Curvature (degree)	1.01	0.14	0.79	1.00	1.00	1.00	3.37
Sky Ahead	0.75	0.44	0.0	0.0	1.0	1.0	1.0
Objects	0.79	0.41	0.0	1.0	1.0	1.0	1.0
Intersections	3.56	2.96	0.0	1.0	3.0	5.0	15.0
Block Length (mi)	0.16	0.13	0.02	0.09	0.13	0.18	1.04
Speed Limit (mph)	38.30	6.54	25.0	35.0	40.0	40.0	70.0
AADT (in 1000s)	22.85	11.37	0.99	14.42	20.80	30.08	61.09
AADT (in 1000s per lane)	5.80	2.15	0.25	4.44	5.55	7.06	13.63
50th Percentile Speed	29.69	8.75	3.00	24.35	29.67	34.49	62.90
85th Percentile Speed	38.56	8.66	13.00	33.65	38.38	42.79	80.00
95th Percentile Speed	43.70	8.29	23.81	38.56	43.07	47.05	89.00
All Crash Count	6.06	6.61	0.0	1.0	4.0	8.0	41.0
Injury Crash Count	1.88	2.45	0.0	0.0	1.0	3.0	16.0
Fatal Crash Count	0.04	0.21	0.0	0.0	0.0	0.0	2.0

Variable	*Mean*	*STD*	*Min*	*25%*	*50%*	*75%*	*Max*
All Crash Count (/Mile)	11.01	11.72	0.0	3.0	7.5	15.0	83.0
Injury Crash Count (/Mile)	3.34	3.95	0.0	0.0	2.0	4.3	26.0
Fatal Crash Count (/Mile)	0.05	0.028	0.0	0.0	0.0	0.0	2.0

Table 6-6 Statistical Distribution of Collected Data for Arterial Sections in Rural Areas

Variable	*Mean*	*STD*	*Min*	*25%*	*50%*	*75%*	*Max*
Length (miles)	0.55	0.25	0.19	0.34	0.50	0.71	1.08
Lane Width (ft)	11.86	0.87	9.11	11.46	11.91	12.49	13.36
Lane ≥ 12 ft (dummy)	0.44	0.50	0.0	0.0	0.0	1.0	1.0
Ln (Lane Width)	2.47	0.08	2.21	2.44	2.48	2.52	2.59
Number of Lanes	2.75	0.98	2.00	2.00	2.00	4.00	4.00
Median (dummy)	0.37	0.49	0.0	0.0	0.0	1.0	1.0
Nontraversable Median (dummy)	0.05	0.21	0.0	0.0	0.0	0.0	1.0
Median Width (ft)	4.60	6.53	0.00	0.00	0.00	11.41	25.70
Shoulder (dummy)	0.89	0.32	0.0	1.0	1.0	1.0	1.0
Shoulder Width (ft)	8.99	5.19	0.00	5.61	9.30	12.00	21.70
Sidewalk (dummy)	0.60	0.49	0.0	0.0	1.0	1.0	1.0
Bike Lane (dummy)	0.05	0.21	0.0	0.0	0.0	0.0	1.0
Bus Stop (dummy)	0.10	0.30	0.0	0.0	0.0	0.0	1.0
Parking	0.03	0.18	0.0	0.0	0.0	0.0	1.0

Variable	***Mean***	***STD***	***Min***	***25%***	***50%***	***75%***	***Max***
Lane (dummy)							
Num. Parked Cars	3.24	5.66	0.00	0.00	0.00	4.50	28.00
Parked Cars (/Mile)	8.11	15.27	0.00	0.00	0.00	10.06	69.22
Curve Length (ft)	2892.71	1330.89	989.00	1810.00	2665.00	3740.88	5702.07
Euclidean Length (ft)	2891.86	1334.57	986.28	1768.92	2662.20	3745.43	5636.93
Curvature (degree)	1.00	0.01	0.97	1.00	1.00	1.00	1.05
Sky Ahead (dummy)	0.84	0.37	0.0	1.0	1.0	1.0	1.0
Objects (dummy)	0.41	0.50	0.0	0.0	0.0	1.0	1.0
Intersections	2.94	2.44	0.0	1.0	2.0	4.0	10.0
Block Length (mi)	0.21	0.21	0.06	0.09	0.11	0.19	1.02
Speed Limit (mph)	38.49	10.61	15.0	30.0	35.0	40.0	65.0
AADT (in 1000s)	7.82	7.04	0.31	2.78	5.53	10.99	32.81
AADT (in 1000s per lane)	2.65	2.04	0.16	1.20	2.03	3.57	9.36
50th Percentile Speed	34.39	11.63	4.00	27.76	32.38	40.88	67.38
85th Percentile Speed	42.39	11.36	11.00	36.00	40.62	48.40	73.90
95th Percentile Speed	49.21	10.13	33.00	42.10	47.86	54.52	77.95
All Crash Count	2.40	4.14	0.0	0.0	1.0	3.0	26.0
Injury Crash Count	0.62	1.52	0.0	0.0	0.0	1.0	11.0
Fatal Crash Count	0.02	0.13	0.0	0.0	0.0	0.0	1.0

Variable	***Mean***	***STD***	***Min***	***25%***	***50%***	***75%***	***Max***
All Crash Count (/Mile)	4.76	7.54	0.00	0.00	2.00	4.50	35.00
Injury Crash Count (/Mile)	1.21	2.57	0.00	0.00	0.00	1.50	15.00
Fatal Crash Count (/Mile)	0.02	0.13	0.00	0.00	0.00	0.00	1.00

6.5. Modeling Speed

6.5.1. Linear Regression

Linear regression is a statistical method used to model the relationship between a dependent variable and one or more independent variables. It assumes a linear relationship exists between the dependent variable and each independent variable (Yao & Li, 2014). The goal of linear regression is to find the best-fit line or plane that describes this relationship, which can be used to predict the dependent variable's value based on the independent variables' values (Aalen, 1989). In this study, we employed a multiple linear regression model to analyze and predict speed. The model enabled us to examine the relationship between speed and various independent variables, such as lane width and other geometric variables, annual average daily traffic, and roadside variables. The relationship between each independent variable and the dependent variable is determined by holding all other variables in the regression equation constant.

6.5.2. Urban Arterial Speeds

The speed modeling started with a scatterplot of lane width vs. 85th percentile speed for UDOT urban arterials (see Figure 6-5). This dataset includes 320 roadway sections. There appears to be a weak but upward sloping relationship between the two. The simple correlation coefficient between the two is 0.105, significant at the 0.065 level, short of the standard of 0.05. We would expect a correlation coefficient as large as lane widths by chance 6.5 percent of the time. The conventional significance level used in most statistical studies is 0.05, suggesting we would expect an effect this large by chance only 5 percent of the time (or for only one out of 20 random samples if there is no relationship between lane width and speed). Of course, this disregards the effect of any confounding variables such as number of lanes or presence of a non-traversable median.

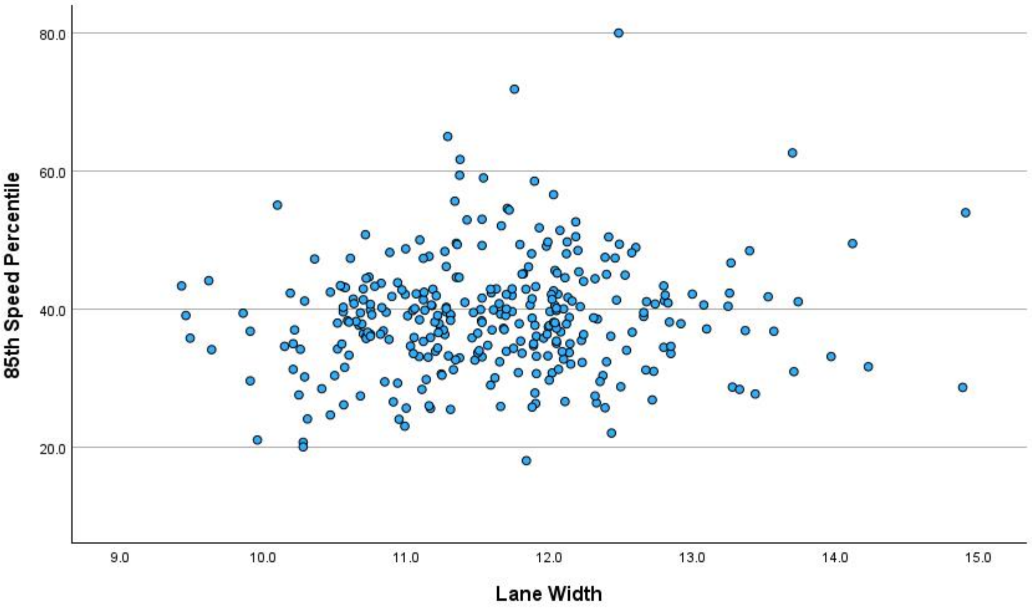


Figure 6-5 Scatterplot of Lane Width (in ft) vs. 85th Percentile Speed (in mph) for UDOT Urban Arterials

We then estimated multiple regression models using the urban area dataset. The most significant variables were found after estimating numerous regression models with different sets of variables available in our dataset.

We began by modeling the 50th percentile using StreetLight speed data. The 50th percentile speed is the speed at or below which 50 percent of the drivers travel on a road section. It is the median speed of travel. The 50th percentile speed is taken from speed data collected during a 24-hour weekday period, as was ours. Controlling for other variables, the 50th percentile speed for our sample had a weak relationship to lane width. While the variable lane width had a positive sign, implying faster speeds with wider lanes (as expected), the significance level of lane width was 0.149, short of the standard 0.05 level.

Next, we modeled the 85th percentile speed in terms of our set of independent variables, following the same procedure as for the 50th percentile or median speed, testing different sets of independent variables. The 85th percentile speed is often used by traffic engineers and planners to represent the upper end of the speed range. Posted speed limits are often based on 85th percentile speeds. The results demonstrate that several variables significantly impact the 85th percentile speed driven on a given roadway section, including lane width. In the final model, only statistically significant independent variables were retained.

The R^2 of the model is 0.405, meaning that the model explains just over 40 percent of the variance in the 85th percentile speed. We tested for multicollinearity and there is none. The highest variance inflation factor (VIF) is 1.334, where values greater than 5.0 signal multicollinearity. We tested logged forms of the dependent and independent variables (the non-binary variables), with no significant change in results.

For the 85th percentile speed, the lane width's significance level is 0.02, a result that would not be expected by chance. Based on the lane width's regression coefficient value of 1.012 compared to its value in the 50th percentile speed model of 0.674, lane width appears to have more impact on higher speed traffic than on average speed traffic. Table 6-7 presents the best-fit regression model for the 85th percentile speed on UDOT urban arterials.

Table 6-7 Linear Regression Model for 85th Percentile Speeds on UDOT Urban Arterials

Variable	*Coefficient*	*Std. error*	*t-statistic*	*p-value*
(Intercept)	16.689	5.666	2.945	0.003
Lane width (ft)	1.012	0.431	2.346	0.020
Number of lanes	1.090	0.303	3.602	<0.001
*Non-traversable median**	-3.720	1.060	-3.508	0.001
Parked cars (/mile)	-0.041	0.011	-3.607	<0.001
*Sky ahead**	2.004	0.937	2.139	0.033
*Objects**	-2.789	0.985	-2.832	0.005
Block length (ft)	0.005	0.001	8.919	<0.001
AADT (in 1000s per lane)	0.650	0.172	3.779	<0.001
R^2				0.405

**Binary variables*

Following this logic, we decided to model the 95th percentile speed for our sample of UDOT urban arterials. The 95th percentile speed represents the uppermost end of the speed range and is also used by traffic engineers and transportation planners, though not as pervasively as the 85th percentile speed. The regression coefficient of lane width is 1.088 and the significance level is 0.011, showing again that lane width has a greater impact on vehicle speed at the upper end of the speed range. Table 6-8 presents the best-fit regression model for the 95th percentile speeds on urban arterials.

Table 6-8 Linear Regression Model for 95th percentile Speeds on UDOT Urban Arterials

Variable	*Coefficient*	*Std. error*	*t-statistic*	*p-value*
(Intercept)	20.809	5.620	3.703	0.000
Lane width (ft)	1.088	0.428	2.543	0.011
Number of lanes	1.282	0.300	4.271	0.000
Non-traversable median*	-3.953	1.052	-3.759	0.000
Parked cars (/mile)	-0.041	0.011	-3.621	0.000
Sky ahead*	1.808	0.929	1.947	0.052
Objects*	-3.282	0.977	-3.360	0.001
Block length (ft)	0.005	0.001	8.982	0.000
AADT (in 1000s per lane)	0.591	0.170	3.467	0.001
R^2				0.421

**Binary variables*

Controlling for other variables, each *additional foot of lane width* leads to an *increase in both the 85th percentile speed and the 95th percentile speed of more than 1 mph.* The difference between a roadway with 14-foot lanes and 10-foot lanes would be more than 4 mph. This conclusion comes with caveats. First, our sample is large but not very large. Second, our sample consists solely of state-owned and operated arterials in Utah. There is almost certainly less variance in the dataset than there would be if collectors were included in the dataset or locally owned arterials were included in the dataset. Third, while we tested for inter-rater reliability, there was an element of subjectivity in different raters' estimates of independent variables. StreetLight speed data are also based on a sample, albeit a large one.

Regarding the other variables, the number of lanes has a positive impact on speed. Specifically, for *each additional lane, the 85th percentile speed increases by 1.09 mph*. Therefore, adding two lanes to a roadway (one in each direction) will result in about the same speed increase as increasing lane width by two feet. This observation has also been shown in road diet projects where a reduced number of lanes results in lower speeds since the prudent driver sets the pace on the roadway with only one lane in each direction. A similar relationship is observed for block length within the roadway section. The results indicate that the longer the blocks along the roadway, the higher the midblock speed.

Conversely, non-traversable medians in a roadway can significantly reduce speed. In fact, non-traversable medians are the most effective variable in *reducing 85th percentile speeds by 3.72 mph.* The objects variable represents the extent of roadside objects alongside the roadway. Hence, it can be concluded that more buildings, trees, and other objects alongside a roadway section can reduce drivers' speed by nearly 3 mph. Sky ahead has about two thirds this effect. Additionally, the coefficient of on-street parking shows that user's perception of the road can be influenced by side friction. Therefore, the "width" of the road is mostly influenced by drivers' perceptions, which affect the speed they drive.

It is important to note that the variables included in this model were selected after searching through all collected variables. The excluded variables either had unexpected signs or were insignificant in the roadway speed model. There was one exception. AADT per lane in thousands was one of those variables with a positive sign and a statistically significant p value. Due to congestion, it was expected that the sign would be negative. Apparently, over the course of a 24-hour period, congestion is not a factor on state urban arterials. Indeed, perhaps due to platooning, faster vehicles set the pace for slower vehicles.

6.5.3. Rural Arterial Speeds

The same approach was used for the dataset of rural areas to find the best speed model, including 61 sections. It is important to note that the limited sample size of the rural area was due to the lack of speed data for many rural sections. However, we believe that the speed model developed based on the limited data provides conclusive results demonstrating the relationship between speed, lane width, and other roadway variables.

We began by inspecting a scatterplot of lane width vs. 85th percentile speed (see Figure 6-6). There appears to be an upward sloping relationship between the two, though there is a lot of scatter around the best fitting regression line. The simple correlation coefficient between the two is 0.271, which is significant at the 0.035 level. Of course, this disregards any effect of confounding variables.

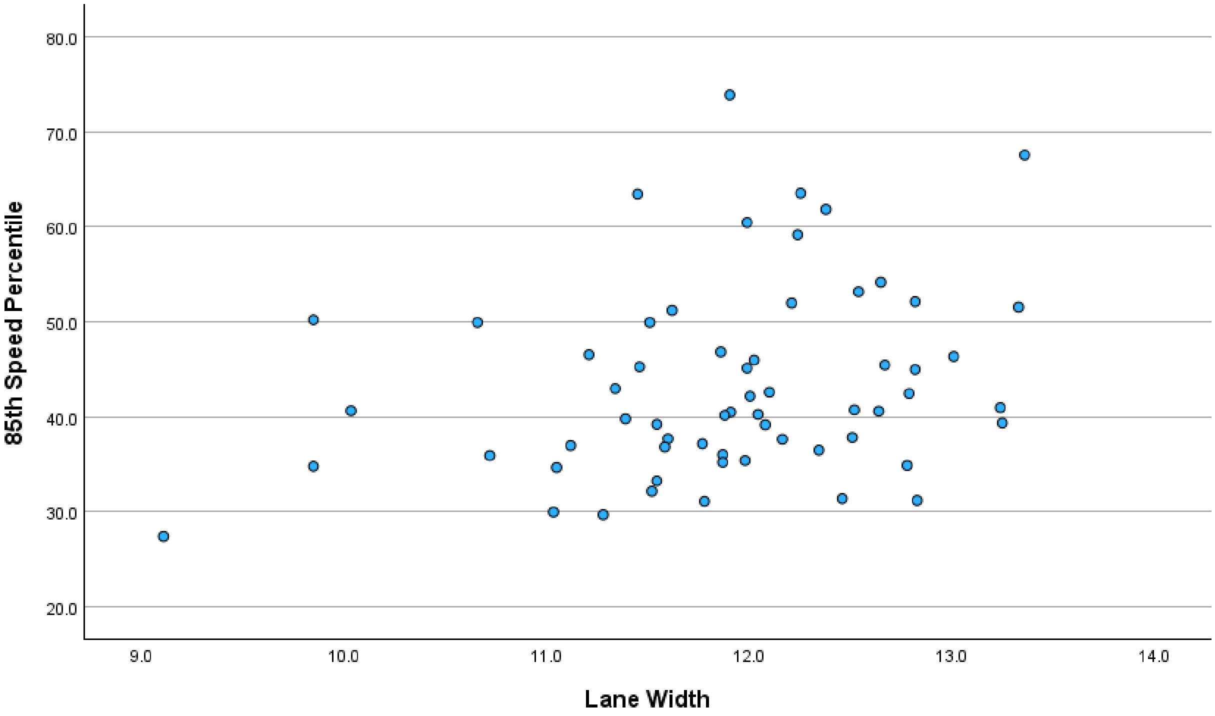


Figure 6-6 Scatterplot of Lane Width (in ft) vs. 85th Percentile Speed (in mph) for UDOT Rural Arterials

We then estimated multiple regression models using the rural area dataset. Table 6-9 displays the regression model results for the 85th percentile speed in rural areas. Due to the limited sample size, only a few significant variables were found with expected signs in the speed model. Upon initial inspection, it can be seen that lane width is significantly correlated with speed in rural areas. The coefficient of lane width suggests that *an additional foot of lane width in rural areas can increase speed by 3.9 mph*. Comparing the significance level and coefficient estimate of lane width in urban and rural areas, speed modeling shows that lane width can have a more significant impact on speed in rural areas. This may be due to the complex design elements present in urban areas, compared to rural areas, that can influence user driving behavior.

Table 6-9 Linear Regression Model for 85th Percentile Speeds in Rural Areas

Variable	*Coefficient*	*Std. error*	*t-statistic*	*p-value*
(Intercept)	-4.241	14.037	-0.302	0.764
Lane width (ft)	3.879	1.119	3.466	0.001
Number of lanes	2.041	1.073	1.903	0.062
Sidewalk[*]	-11.085	2.313	-4.793	0.000
Block length (ft)	0.002	0.001	2.230	0.030
R^2				0.493

[*] *Binary variables*

Another variable that significantly impacts speed in rural areas is the presence of sidewalks. Table 6-9 reveals that *the existence of sidewalks adjacent to roadways can reduce drivers' speed by 11.085 mph*. We speculate that sidewalks in rural areas (including small towns) are not that significant in their own right as a cross-sectional design element, but rather that they represent the degree of development of the roadside area, which tends to alert drivers and reduce their speed. Longer block lengths were found to increase speed in rural areas, similar to urban areas. No other independent variables, including shoulders and medians, were statistically significant.

6.6. Modeling Crashes

6.6.1. Count Regression Models

Traffic safety studies have used different statistical models to examine the association between cross-section design features and crash frequency, such as Poisson and negative binomial models (Abdel-Aty and Radwan, 2000; Hadi et al., 1995; Jones et al., 1991; Lord and Park, 2008; Milton and Mannering, 1998; Poch and Mannering, 1996; Shankar et al., 1995; Zhao et al., 2016), zero-inflated negative binomial models (Shankar et al., 1997; Carson and Mannering, 2001; Lee and Mannering, 2002), negative binomial with random effects models (Shankar et al., 1998), Conway–Maxwell–Poisson generalized linear models (Lord et al., 2008), negative binomial with random parameters (Anastasopoulos and Mannering, 2009), dual-state negative binomial Markov switching models (Malyshkina et al., 2009; Malyshkina and Mannering, in press) (Malyshkina and Mannering, 2010).

Our dependent variables are crash counts on a roadway section, excluding intersection crashes because they presumably result from conflicting movements at intersections far more than midblock speeds. Two basic methods of analysis are available when the outcome variable is a count, with nonnegative integer values, many small values, and few large ones. The methods are Poisson regression and negative binomial regression.

The two models—Poisson and negative binomial—differ in their assumptions about the distribution of the dependent variable. Negative binomial regression is appropriate when the dependent variable is over dispersed, meaning that the variance of counts is greater than the mean. Popular indicators of overdispersion are the Pearson and $\chi 2$ statistics divided by the degrees of freedom, so-called dispersion statistics. If these statistics are greater than 1.0, a model is said to be over dispersed (Hilbe, 2011, pp. 88, 142). By these measures, we have overdispersion of crash counts in our data sets, and the negative binomial model is more appropriate than the Poisson model.

We started with three outcome variables—total crashes, injury crashes, and fatal crashes—but reduced it to two because fatal crashes are so rare. Only 3 percent of roadway sections in our sample experienced fatal crashes in 2021.

Another statistical complication results from the fact that the variables of interest, crash counts and injury crash counts, were initially count variables for an entire section of roadway, each of varying length. Upon converting it to a total crash rate per mile and an injury crash rate per mile, the resultant output consisted of decimal values, which were subsequently rounded to restore the variable to its original count format, representing the total number of crashes and injury crashes per mile. This allowed us to apply a count model to the resulting dependent variable, as is the norm in crash analysis.

A fourth statistical complication is the excess number of zero values for the injury count variable. For urban arterials, the frequency distribution of total crash counts follows a negative binomial distribution rather closely, and this can be modeled in a single stage. In contrast, 32 percent of urban sections and 64 percent of rural sections have no injury crashes. One solution to the problem of “zero inflation” is to estimate two-stage hurdle models. The first stage is the estimation of a binary logistic regression model to distinguish between sections with and without any injury crashes. The second stage is the estimation of a negative binomial regression model for the number of injury crashes for sections with any injury crashes (positive integer values). It is worth noting that each of these models was finalized after a thorough search for the best variables that were significant and produced the expected signs.

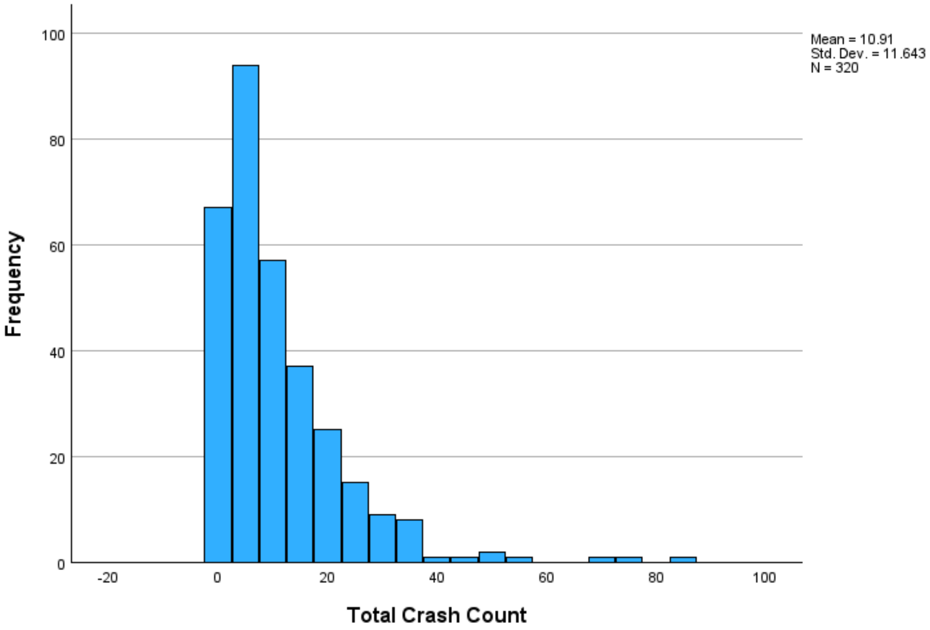


Figure 6-7 Frequency Distribution of Total Crashes per Mile for Urban Arterials without Zero Inflation

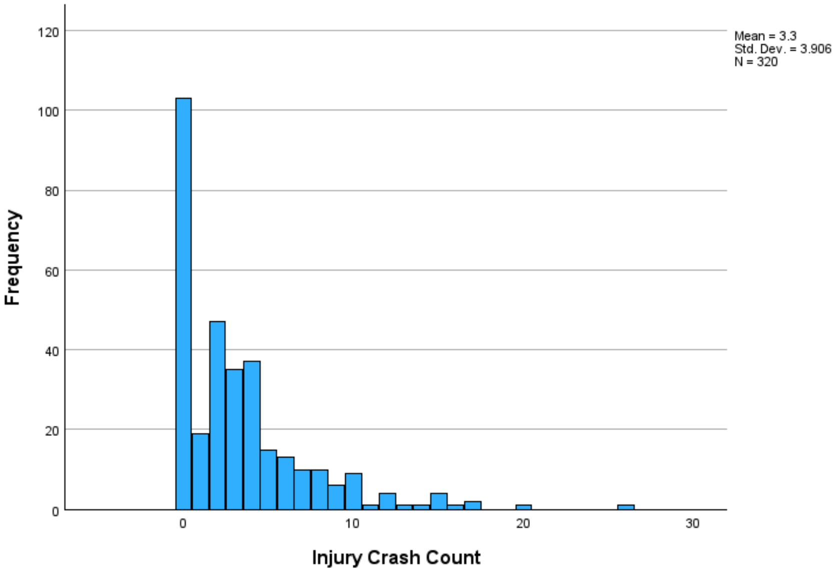


Figure 6-8 Frequency Distribution of Injury Crashes per Mile for Urban Arterials with Zero Inflation

6.6.2. Urban Arterial Crashes

The crash modeling started by estimating multiple models using the urban area dataset. This dataset includes 320 roadway sections, and the most significant variables were found after estimating numerous regression models with different sets of variables available in our dataset.

We began by modeling total crashes per mile, including property damage only crashes (level 1 crashes from levels 1 to 5). Using negative binomial regression, the only variables that proved significant were the number of travel lanes and AADT per lane in thousands of vehicles. More travel lanes suggests more weaving in and out of traffic, as aggressive drivers change lanes carelessly. The preceding discussion of road diets applies here. More AADT per lane in thousands suggests more exposure to potential crashes and less space between vehicles for crash avoidance. Notably, neither lane width nor 85th percentile speed (nor, parenthetically, 95th percentile speed) proved to be significant predictors of total crashes per mile. One could certainly imagine that lower speed environments, and the stop-and-go traffic that accompanies them, lead to more fender benders that offset more serious crashes in higher speed environments. One could also imagine that narrower lanes cause drivers to exercise greater caution since the driving environment is less forgiving, one effect offsetting the other.

We next estimated a two-stage hurdle model for injury crashes per mile (level 2 through level 5). Hurdle modeling is a statistical technique for analyzing count data with many zero values. In such cases, traditional count models like Poisson or negative binomial regression may not be appropriate since they assume that the count variable follows a particular distribution and does not account for the excess zeros (McDowell, 2003). Hurdle modeling addresses this issue by breaking down the count data into two parts: a binary part representing the presence or absence of the event of interest (i.e., whether the count is zero or not) and a count part representing the number of such events (i.e., positive counts). The binary part is modeled using binary logistic regression, while the count part is modeled using a truncated count model (e.g., zero-truncated Poisson or negative binomial regression). By separately modeling the binary and count parts of the data, we attempt to account for the excess zeros in our crash data and improve the accuracy of the statistical analysis.

6.6.3. Binary Logistic Regression of Injury Crash Occurrence

Binary logistic regression is a statistical method used to analyze and model the relationship between a binary dependent variable (a variable with two possible outcomes) and one or more independent variables. In logistic regression, the dependent variable is modeled as a function of the independent variables using a logit function, an S-shaped curve that maps any real-valued input to a value between 0 and 1 (Hilbe, 2011). The logit function is used to estimate the probability that the dependent variable takes a particular value given the values of the independent variables. This tool has been used as a part of our hurdle model to capture the association between the occurrence/non-occurrence of crashes with various predictor variables.

Using the urban dataset, our best-fitting model for injury crash occurrence includes both lane width and 85th percentile speed, plus the variables that proved significant for total crash counts (see Table 6-10). Both are significant at the 0.05 level and have positive signs. The relationship between speed and injury crashes is self-explanatory. The relationship between lane width and injury crashes may be explained by more cautious driver behavior when there is less clearance between vehicles in multilane cross sections.

The coefficient value for lane width in the binary logistic model is 0.325, meaning that an increase in lane width by one unit (ft) is associated with an increase in the odds of a crash occurring by a factor of *e* raised to 0.325 power, or 1.383. This is referred to as an odds ratio. Based on the final column in Table 6-10, *a one-foot increase in lane width is accompanied by a 38.3 percent increase in the odds of roadway section having an injury crash*. The p-value for this coefficient is 0.025, indicating statistical significance at a high confidence level.

The coefficient value for 85th percentile speed in the binary logistic model is 0.046, meaning that an increase in lane width by one unit (mph) is associated with an increase in the odds of a crash occurring by a factor of *e* raised to 0.046 power, or 1.047. This, again, is referred to as an odds ratio. Based on the final column in Table 6-10, *a one-mph increase in the 85th percentile speed is associated with a 4.7 percent increase in the odds of an injury crash*. The p-value for this coefficient is 0.012, indicating statistical significance at a high confidence level.

Other significant variables in the binary crash model are the number of lanes and AADT per lane in thousands. Both have the expected positive signs. More travel lanes suggest more weaving in and out of traffic, as aggressive drivers change lanes carelessly. More AADT per lane suggests more exposure to potential crashes and less space between vehicles for crash avoidance.

Table 6-10 Binary Model of Injury Crash Occurrence in Urban Areas

Variable	***Coefficient***	***Std. error***	***Wald statistic***	***p-value***	***exp (coeff)***
(Constant)	-7.674	1.891	16.464	0.000	0.000
Lane width (ft)	0.325	0.145	5.025	0.025	1.383
Number of lanes	0.331	0.102	10.477	0.001	1.393
AADT per lane	0.295	0.069	18.195	0.000	1.343
85th percentile speed	0.046	0.018	6.282	0.012	1.047
pseudo R^2				0.204	

**Binary variables*

6.6.4. Negative Binomial Regression

In this study of injury crashes, negative binomial regression has been utilized as a part of our hurdle model after accounting for zero inflation. We modeled positive values of injury crashes. Only two independent variables proved statistically significant: number of lanes and AADT per lane. Neither lane width nor 85th percentile speed proved statistically significant. This seems to fly in the face of our earlier result that the occurrence of injury crashes as a binary variable is related to both lane width and 85th percentile speed. However, the whole idea of a hurdle model is that different processes may be at work in determining whether any event occurs, and if so, how many of such events occur. The expected number of crashes is just the product of the probability of crash and the expected number of crashes if any occur. Therefore, we can say with come confidence that wider lanes on urban arterials are associated with more injury crashes.

6.6.5. Rural Arterial Crashes

The unavailability of sufficient speed data has limited the confidence level of the modeling results for rural arterials. This is due to the comparatively small sample available for the rural arterials, rendering our attempts to model total and injury crashes ineffective vis-à-vis geometric and other variables. For rural areas, our sample size of homogeneous (uniform) roadway sections was only 61 sections.

Similar to urban areas, the modeling started by looking at the distribution of crash counts in rural areas. Figure 6-7 depicts the distribution of total rural area crashes per mile; as shown, it borders on zero-inflated but, for the sake of simplicity, will be analyzed with a negative binomial regression model. In contrast, Figure 6-8 shows the distribution of rural area injury crashes per mile, which is clearly zero-inflated. Therefore, we opt to use a hurdle model to estimate the latter. Only one rural section experienced a fatal crash in 2021, and the sample cannot be analyzed for fatal crashes.

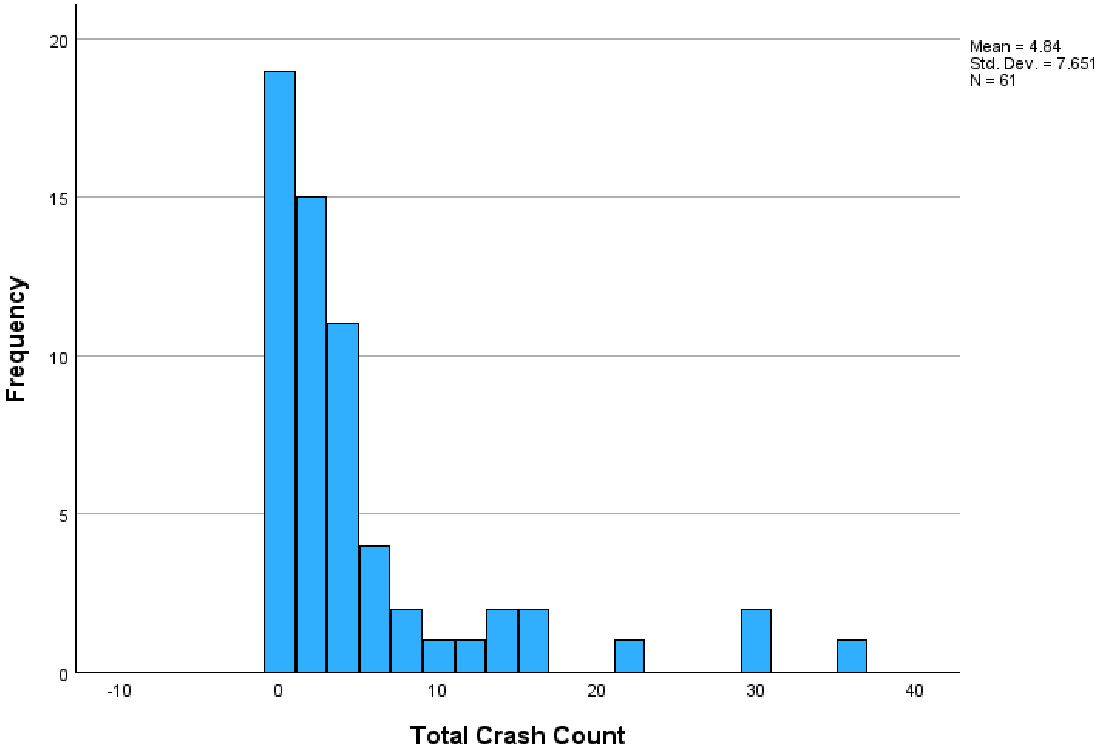


Figure 6-9 Frequency Distribution of Total Crashes per Mile for Rural Arterials without Zero Inflation

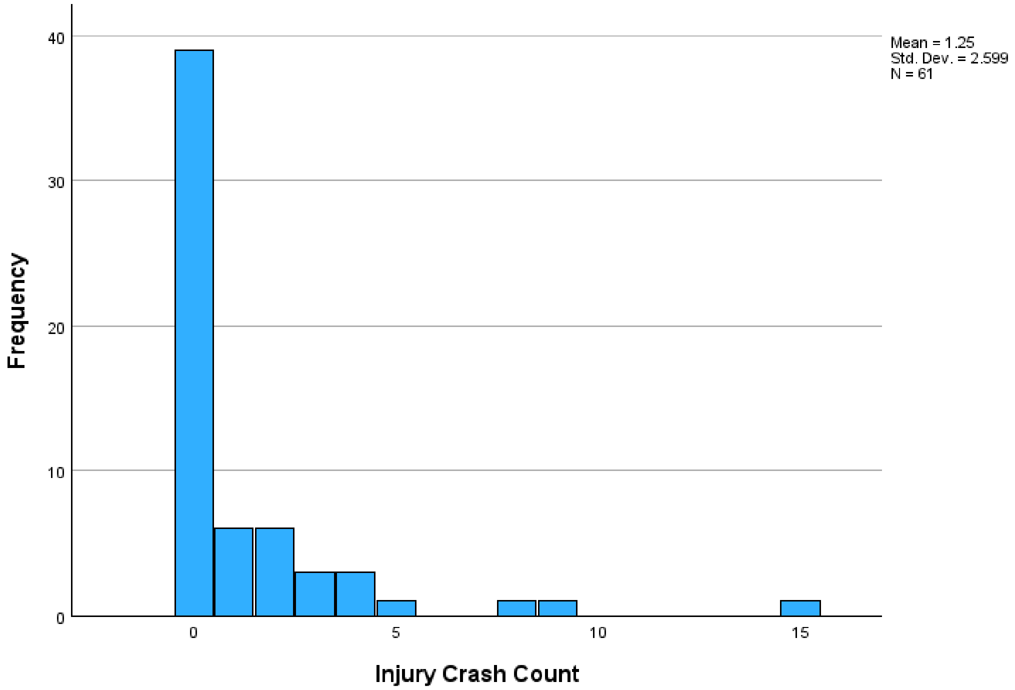


Figure 6-10 Frequency Distribution of Injury Crashes per Mile for Rural Arterials with Zero Inflation

We began by modeling total crashes per mile, including property damage only crashes (levels 1 to 5). Using negative binomial regression, the only variables that proved significant were the number of travel lanes and AADT per lane in thousands of vehicles. More travel lanes suggest more weaving in and out of traffic, as aggressive drivers change lanes carelessly. More AADT per lane suggests more exposure to potential crashes and less space between vehicles for crash avoidance. None of the other independent variables even approached statistical significance. Specifically, neither lane width nor 85th percentile speed (nor, parenthetically, 95th percentile speed) proved to be significant predictors of total crashes per mile. This result is identical to the result for total vehicle crashes per mile on urban arterials.

For injury crashes per mile, we comprehensively analyzed multiple independent variables, including speed, lane width, AADT per lane in thousands, and the number of lanes. The binary component of the hurdle model produced no significant variables at the 0.05 level, though AADT per lane in thousands approached statistical significance. In the second part of the hurdle model, we applied a negative binomial regression model to investigate the crash count (positive counts) for rural arterials, similar to our modeling for urban arterials. This piece of the model estimates the relationship between positive crash counts and other road variables. The results indicate that only number of lanes and AADT per lane in thousands proved significantly associated with the total crash counts. No other variables, including lane width and 85th percentile speed, significantly impacted positive crash counts.

7.0 CONCLUSION AND DISCUSSION

Although reducing lane width on urban arterials can provide more space for additional street features, ensuring safety is a priority when determining optimal lane width. Lane width in urban and rural settings may have different impacts on safety, mixed in the previous studies, even within the same urban or rural setting. Reducing vehicle lane widths is often considered a way to increase road safety, decrease vehicle speed and provide more space for active transportation infrastructure. This research aims at understanding the transportation effects of vehicle lane widths on urban and rural arterials for Utah regarding highway capacity, road safety, pedestrian traffic volume, and agency cost.

This study comprehensively analyzes road design and lane width management while going beyond the conventional 12-foot width dictated by state standards. The interviews with five DOTs included questioning on design criteria, design exceptions, and completed projects or future projects on urban and suburban roadways involving lane width reduction. The significant findings presented in five interviews confirm that reducing lane width is considered as a means of reducing speed and accommodating other travel modes. Nevertheless, simply reducing lane width may not provide significant benefits in reducing speeds. Instead, it should be coupled with other low-speed strategies, such as traffic calming. Furthermore, lane repurposing, enabling integrated walking, biking, transit, and passenger rail, has proven to be highly efficient in mitigating speed and crash rates. However, lane width standards among these states vary due to several factors, including geographical location of roadways (urban or rural areas), road classification, user needs, access management, and desired speed. These elements, especially the geographical context of roadways, influence the decision-making process regarding lane width regulations, leading to regional discrepancies in their implementation. For instance, Vermont State Design Standards utilize 11-foot lanes for urban but 12-foot widths for rural areas with higher-speed, free-flowing principal arterials.

The survey of AASHTO committee members aimed at exploring lane-width reduction projects across the United States along with their associated impacts. The 13 surveyed committee members are from the Departments of Transportation (DOTs) of Michigan, Ohio, Alabama, Maine, California, Tennessee, Washington State, Minnesota, Alaska, Arizona, Montana, Kentucky, and Texas. The survey questionnaire consists of three segments: i) inquiry about roadway design standards in the states, ii) investigation of lane-width reduction projects within their jurisdictions, and iii) gathering of the committee members' affiliations, contact information, and interest. All 13 respondents reported their own statewide roadway design manuals, standards, and policies that regulate vehicle lane widths and/or limit the reduction of vehicle lane widths. All ASTRO members of the survey mentioned a design exception process where lane width reductions can be proposed, reviewed, and approved for specific conditions considering road classification, ADT, speed, safety, project needs and funding, impacts on property and environment, provision of other transport facilities, and so on. Moreover, the response regarding the agency's goals in having minimum lane width policies and/or lane-width reduction guidelines showed that improving traffic safety (92.3%), improving safety for pedestrians and bicyclists (69.2%), increasing active transportation use (61.5%), reducing construction and maintenance costs (61.5%), and reducing vehicle speeds (53.8%) are the primary goals.

This quantitative analysis investigates the relationship between lane width, speed, and crash rates to understand road safety and transportation impacts. Data from 320 urban and 61 rural arterial sections in Utah were analyzed. Results consistently support reducing lane widths in Utah. Narrower urban lanes decrease speeds without raising crash rates. Extra space gained from narrower lanes can enhance safety. Urban areas' speed analysis revealed each foot reduction lowering speeds. Influencing factors include lanes, median presence, on-street parking, roadside objects, and block length. Rural areas' speed analysis was inconclusive due to limited samples. Safety modeling showed no direct relation between lane width and crash counts per mile in both areas. However, urban injury crashes linked to lane width and speed, wider lanes and higher speeds increasing injury likelihood. Factors for crash counts were lanes and AADT per lane. The speed models demonstrate the significant influence of lane width on speed for both urban and rural arterials, with narrower lanes consistently associated with lower speeds. Additionally, other variables such as the number of lanes, non-traversable medians, on-street parking density, roadside objects, and average block length also impact speed on urban arterials. For rural arterials, lane width, average block length, and the presence of a sidewalk play significant roles. Regarding safety, the modeling reveals a positive relationship between injury crash counts in urban areas and lane width, as well as 85th percentile speeds. Narrower lanes and lower speeds correlate with a reduced likelihood of injury crashes, underscoring the potential safety benefits of lane narrowing.

However, total crash counts do not directly correlate with lane width in either urban or rural areas, as minor crashes on narrow, low-speed roadways offset more severe crashes on wider, high-speed roadways. For rural areas, the results were inconclusive due to the limited sample size, with only the number of lanes and AADT per lane showing significant associations with total and injury crash counts. In conclusion, the results from quantitative analysis support reducing lane widths to enhance road safety and urban transportation infrastructure. Decision-makers can use these findings to improve road safety and performance.

All parts of this study suggest the potential to reduce minimum travel lane widths in Utah from the blanket standard of 12 feet to more context-sensitive and variable standards. Literature reviewed unequivocally confirms the potential impact of narrower travel lanes on speed, safety, and other transportation aspects. The surveys of state DOTs and 15 AASHTO members offer critical guidance for the subsequent statistical analyses. The statistical analyses yield important findings for both urban and rural arterials. In urban areas, the narrowing of lane widths leads to significant reductions in vehicle speeds without increasing crash rates. The additional space gained from narrower lanes presents opportunities for implementing various safety and pedestrian-friendly enhancements. Consequently, we recommend revising the current minimum lane width standard, particularly in low-speed, highly urbanized areas, and potentially exploring further reductions in specific cases, while also considering exceptions for areas with heavy truck traffic.

In summary, this study provides compelling evidence supporting the feasibility and safety advantages of reducing lane widths on Utah's urban arterials. These findings hold valuable insights for transportation policymakers and practitioners in shaping lane width policies to enhance road safety and operational performance. However, further research with larger sample sizes in rural areas is essential to deepen our understanding of safety impacts. Implementing the recommended revisions has the potential to optimize Utah's transportation infrastructure, accommodating a diverse range of users while ensuring safer roadways for all.

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APPENDIX A: SURVEY QUESTIONNAIRE

Survey Questionnaire

We are a research team in the Metropolitan Research Center at the University of Utah conducting a research project, “Transportation Benefits and Costs of Reducing Lane Widths on Urban and Rural Arterials,” funded by the Utah Department of Transportation. As part of the project, we are surveying DOTs to understand lane width reduction projects, policies, and standards and their associated benefits and costs.

While reducing vehicle lane widths is often considered a way to decrease vehicle speed and increase road safety, comprehensive research is lacking on practices and their impact. The results of this survey are expected to clarify the state of current practices, highlight exemplary road renovation projects, and provide insights for future practice.

The following questionnaire requires 5-15 minutes to complete. The data collected will be used solely for academic purposes and shared with survey participants upon request.

Section A. Statewide design standards

1. Do you have statewide roadway design standards, manuals, and policies that regulate vehicle lane widths and/or limit a reduction of vehicle lane widths?

1. Yes
2. No (*You can skip this section and go to the Section B.)
3. Not Sure (*You can skip this section and go to the Section B.)

2. Please provide more details about standards, manuals, and policies. Document names, web sources, and links for reference are requested.

(Please type in)

3. What are your agency’s goals and expectations in having minimum lane width policies and/or lane width reduction standards? Please select all possible answers

1. Improving traffic safety
2. Improving safety for bicycles and/or pedestrians
3. Reducing vehicle speeds
4. Increasing bicycle and/or pedestrian use
5. Reducing construction and/or maintenance costs
6. Not sure

7.	Other.

(Please type in)

4. Does your DOT have a design exception process where lane width reductions can be proposed, reviewed, and approved?

1.	Yes
2.	No (*You can skip the following questions and go to the Section B.)

5. Are there specific conditions (e.g., speed, traffic volume, functional class, zoning) that enable reduced lane widths to be considered? If so, what are these conditions?

(Please type in)

6. Who has the authority to approve lane width reduction requiring design exceptions? Please describe the approval process of lane width reduction below the minimum width of state regulation.

(Please type in)

Section B. Lane width reduction projects

7. Do you have a lane width reduction project(s) completed, or one(s) that will be implemented in your jurisdiction?

1.	Yes
2.	None (*You can skip this section and go to the last Question)
3.	Not sure (*You can skip this section and go to the last Question)

8. Please select one exemplary project and provide more details about it. Project name, location, web sources, and links for reference are requested.

(Please type in)

9. In considering a lane width reduction project for a specific site, what are the primary objectives of the lane width reduction project? Please select all that apply.

1. Improving traffic safety
2. Improving safety for bicycles and/or pedestrians
3. Reducing vehicle speeds
4. Increasing bicycle and/or pedestrian use
5. Reducing construction and/or maintenance costs
6. Not sure
7. Other.

(Please type in)

10. If applicable, after reducing lane widths, were significant changes observed and/or measured. Please select all possible answers.

1. Change in traffic safety
2. Change in bicycle/pedestrian safety
3. Change in vehicle speeds
4. Change in bicycle/pedestrian volumes
5. Change in construction and/or maintenance costs
6. No significant changes have been observed or measured
7. Not sure
8. Other

(Please type in)

11. [Safety] If applicable, after reducing lane widths, what types of changes were observed and/or measured regarding road safety? Please select all possible answers.

1. Increased crash rate
2. Decreased crash rate
3. Increased crash severity
4. Decreased crash severity
5. No significant changes
6. No significant changes
7. Not sure
8. Other.

(Please type in)

12. [Vehicle speed] If applicable, after reducing lane widths, what types of changes were observed and/or measured regarding vehicle speeds?

1. Increased vehicle speed
2. Decreased vehicle speed
3. No significant changes
4. Not sure

13. [Traffic volume] If applicable, after reducing lane widths, what types of changes were observed and/or measured regarding traffic volume? Please select all possible answers.

1. Decreased traffic volume
2. Increased traffic volume
3. No significant changes
4. Not sure

14. [Pedestrian/bicyclist volume] If applicable, after reducing lane widths, what types of changes were observed and/or measured regarding pedestrian and bicyclist volumes? Please select all possible answers.

1. Increased pedestrian volume
2. Decreased pedestrian volume
3. Increased bicyclist volume
4. Decreased bicyclist volume
5. No significant changes
6. Not sure

15. [Construction/maintenance costs] If applicable, after reducing lane widths, what types of changes were observed and/or measured regarding construction and maintenance costs? Please select all possible answers.

1. Increased construction cost (*compared to regular road construction cost with no lane width reduction)
2. Decreased construction cost
3. Increased maintenance cost
4. Decreased maintenance cost
5. No significant changes
6. Not sure

16. [Road cross-sectional design] If applicable, while reducing lane widths, were there any other physical changes implemented? Please select all possible answers.

1. Multimodal transportation infrastructure (e.g., bicycle lanes, e-scooter lanes)
2. Paved pedway and/or sidewalk width
3. Street trees and/or landscaping
4. Pedestrian refuge island

5. Median
6. Transit shelters
7. On-street parking
8. Traffic calming measures
9. Not sure
10. Other.

(Please type in)

17. [Overall impact] Speaking generally, what are your expectations regarding the impacts of reducing lane widths?

(Please type in)

18. Were there other elements of the lane width reduction project that might have contributed to a decrease in crashes, speed, traffic, and pedestrian volumes besides lane width reduction?

(Please type in)

Contact Information

19. Thank you for your time for completing our survey. Please provide your contact information below. We will e-mail you a link to the online report when it is completed.

- Participant name :
- Position/title :
- Affiliation (organization name) :
- Email address :

APPENDIX B: CONTACT INFORMATION AND AFFILIATION OF RESPONDENT AASHTO MEMBERS

Affiliation	*Name*	*Position*	*Email Address*
Michigan DOT	Nathan Miller	Engineer of Road Design	millern13@michigan.gov
Ohio DOT	Adam Koenig	Administrator	adam.koenig@dot.ohio.gov
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