



RESEARCH

DEVELOPING AN OREGON ACCESS MANAGEMENT BEST PRACTICES MANUAL

FINAL REPORT

RESEARCH ODOT/OTREC

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DEVELOPING AN OREGON ACCESS MANAGEMENT BEST PRACTICES MANUAL

Final Report

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16. Abstract

This Report reviews an Oregon research effort to develop an Oregon Access Management Best Practices Manual. In particular, this research effort develops a resource to help transportation professionals quantify safety and operational effects of various access management strategies, provide measurable criteria to evaluate these access management techniques, and identify data collection practices necessary to successfully perform these assessments. It is the expectation that this manual can be used by engineers, decision makers, and educators to help the transportation community better understand the appropriate application of access management strategies and how to quantify benefits of the various access management options.

This report includes a literature review of safety and operational benefits for a variety of access management configurations. Included in this benefits summary is information about perceived and measured economic impacts of access management even though they are not explicitly included in the companion manual. In addition, this report summarizes example data for access management through the use of case studies, and includes (in the appendix) a standalone proposed access management best practices manual. The case studies were used to test practicality of acquiring various data elements and are not directly reflected in the manual.

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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	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	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	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

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	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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This report does not constitute a standard, specification, or regulation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF PHOTOS/FIGURES

1.0 INTRODUCTION

The transportation industry has been aware for several years that there are substantial safety and operational benefits when a transportation system is constructed or retrofitted with strategic access management designs such as shared driveways, raised medians, or driveway restrictions near intersections. The Transportation Research Board (TRB) publishes a key document known as the Access Management Manual (*2003*). This TRB document addresses access management principles, techniques, and basic design configurations. It also includes recommendations for state and local involvement, case examples of access management techniques, public information strategies, and legal considerations. Though this TRB document provides substantial information regarding the application of access management principles and strategies, it does not provide a means for decision makers to make data-driven decisions that can show performance measures or provide information to help these decision makers or designers quantify the expected benefits of potential candidate treatments. Access management has met with significant resistance from the business community as business owners often perceive access management treatments as a means for restricting access to businesses adjacent to the public road resulting in perceived harm to the businesses. It is important to develop a best practices document for the State of Oregon that includes decision-support tools that will help quantify the anticipated results and determine the costs and benefits of these choices to both the transportation agency as well as to the community.

In recent years, several access management researchers have made headway towards quantifying specific access management benefits, yet this information is not readily available and may not be applicable to all regions. For example, states where access management has been given substantial attention (Florida, Texas, Colorado, and Iowa for example) have unique issues (such as older drivers, unfamiliar drivers, frontage road systems) that do not completely capture conditions in the State of Oregon or other states.

The research summarized in this report reviews the literature reviewed by the project team as well as the development process for an access management best practices document for Oregon. This document addresses potential access management treatments and, where available, their associated performance measures. The document specifically targets safety and operational performance measures, identifies measurable criteria to use for access management evaluations, provides guidance for data collection essential to this assessment, and recommends documentation procedures to help transportation officials assess the effectiveness of access management scenarios following implementation.

The information contained in this report, therefore, summarizes the published literature for safety and operational benefits of access management strategies. This information is included in the literature review (see Chapter 2). In addition, many state agencies develop their own access management guidelines or policies and the state of practice for these various state agencies is included (see Chapter 3). Chapter 4 then introduces the research team's work plan approach including example data collection efforts. Chapter 5 provides summary remarks. Chapter 6 documents the literature used as references for this evaluation. Finally, Appendix A defines common abbreviations and acronyms used throughout the report.

2.0 LITERATURE REVIEW

Access management techniques are effective ways to improve the safety and operation of highway systems while reducing delay and emissions. There are many access management strategies in use, but the effectiveness of these measures is often unknown. This literature review introduces common access management techniques and the information, as published in literature, about performance measures associated with these access management strategies. The primary techniques reviewed in this report include:

- Median Treatment Alternatives,
- Signalized Intersection Spacing,
- Unsignalized Intersection and Driveway Spacing,
- Auxiliary (Left-turn and Right-turn) Lane Installation,
- U-turns as Access Management Strategies, and
- Access Management at Roundabouts and Interchanges.

The direct impacts of access management can be classified into two general categories: traffic safety and traffic operations (including travel time, delay, and traffic flow). Occasionally, indirect impacts are cited in the literature and generally apply to associated economic impacts.

Access management is frequently cited as a systemic approach to improving safety. In general, the impacts of access management are considered to be positive towards enhancing the safety performance of transportation facilities. Gluck, Levinson, and Stover (*1999*) reviewed eleven research efforts that were conducted between 1960 and 1980 and eleven studies conducted since the mid-1980s. They determined that access management had positive impacts on the performance of corridors by reducing crash rates and improving traffic flow rates.

Gluck, Levinson, and Stover (*1999*) also performed a comprehensive safety analysis for 37,500 crashes on 264 roadway segments in 8 states. They developed crash rate indices and crash rates for these roadway segments. Ultimately, they concluded that access management does improve safety. Although the specific relationships vary according to road geometry, travel speeds, and driveway and intersection patterns, this general relationship between safety and access management remained consistent.

Gattis and Hutchison (*2000*) evaluated three roadways in Springfield, Missouri to determine the impacts of access management on delay and crashes. The roadway segments were selected to contrast incrementally increasing levels of access control. Site #1 (the Glenstone-North study segment), for example, included very little access management while Site #2 (the Glenstone-South study site) incorporated the greatest degree of access management. Site #3 (Battlefield Road), on the other hand, was characterized by raised medians within 200 feet of the signalized intersections and a driveway density of roughly one-half that of Site #1. All three segments had similar traffic volumes and features consistent with the abutting region. Gattis and Hutchison recorded the crashes that occurred in the three corridors from 1995 to 1998, and determined that Site #2 (the site with the greatest level of access management) had fewer crashes even though it also experienced the highest vehicle travel speed. During the study period, fatal crashes only occurred along the Site #1 segment.

The known safety and operational performances of specific access management features are highlighted in the following sections. In addition, these sections identify other cited performance measures for access management strategies.

2.1 MEDIAN TREATMENT ALTERNATIVES

One of the most common access management strategies is the use of median treatments to help channelize traffic flow conditions and consequently reduce vehicle conflicts. A considerable portion of the published literature has focused on the safety effectiveness of the various types of medians as well as how the combined use of medians and access density can influence roadway operations and safety. In general, a divided roadway is assumed to have a median with a raised, non-traversable median, though a traversable (flush) median is also a common median alternative. One common traversable median option included in the access management literature is the two-way left-turn lane (TWLTL). Median configurations, in general, remove left-turning vehicles from the adjacent active travel lane, thereby reducing the likelihood of turning conflicts between vehicles in the same direction of travel. Non-traversable medians, however, further separate opposing traffic from turning vehicles or errant straight vehicles. Non-traversable medians, when constructed an adequate width, also provide refuge for pedestrians crossing the street.

At locations with TWLTL configurations, left-turning movements are permitted and are distributed along the roadway segment, whereas roads with raised medians concentrate the left-turn movements at median break locations such as signalized intersections or mid-block crossings. The published research regarding the safety performance of medians has generally focused on two analysis options: (1) modifying undivided highways to add median configurations, and (2) comparing the safety benefits of TWLTLs versus raised medians. This comparison is often based on the number of adjacent driveways and the demand for left turn movements. Additional discussion about driveway frequency and unsignalized access point spacing, particularly for undivided highways, is further reviewed in Section 2.3 of this report.

The addition of a median treatment to a roadway can enhance the operation and safety of the facility. In many cases, adding a median that is raised or flush is accompanied by other facility improvements such as a change in the number of through lanes or a modification in the width of travel lanes. Though it is a challenge to separately evaluate the safety influence for these various roadway modifications, several past studies have summarized the overall safety benefits of the installation of TWLTLs as well as non-traversable raised medians. The following sections address these common roadway conversion scenarios.

2.1.1 Safety Effectiveness of Two-Way Left-Turn Lane Median Treatments

TWLTLs permit the use of a center lane for left turns in both directions of travel. These continuous left-turn lanes transition into a conventional left-turn lane at major intersection locations. The published literature regarding TWLTLs evaluates the safety and operational performance of these median treatments and often contrasts their performance to that of undivided roads. Section 2.1.3 provides additional comparisons between TWLTLs and non-traversable medians as well as an overview of the operational effectiveness of median treatments.

The safety performance of TWLTLs varies based on road lane configuration, traffic volume, driveway density, and a wide variety of other variables common to a road environment. The National Cooperative Highway Research Program (NCHRP) commissioned a study to identify the general impacts of access management. The final report for this effort is NCHRP Report 420 (*Gluck, Levinson, & Stover 1999*). In this study, the authors identified previous research efforts where various researchers had compared the safety enhancements resulting from converting undivided roads to roadways with TWLTL configurations. In general, these studies spanned a period of approximately 20 years and incorporated a variety of road characteristics.

Table 2.1 depicts a summary of the perceived safety implications of converting undivided roads to facilities with TWLTL configurations. The measure of comparison presented in this table is the percent difference in crash frequency and/or crash rate. The methodology the various researchers generally used for the studies (other than those indicated as analysis for comparison sites – see Footnote “a” in Table 2.1) was a simple before-after study approach. Though a good indicator, this analysis approach often ignores other changes in operational trends such as an increase in traffic volume or additional physical changes to the road. As shown in Table 2.1: Crash Experience for TWLTLs, installing a TWLTL at a previously undivided road location will generally result in a reduction in the number of crashes (ranging from 21-percent up to 41-percent); however, one study (*Bowman and Vecellio 1994a*) indicated a reverse safety trend with a substantial increase in suburban arterial crashes. A similar reduction trend is generally observed for crash rates.

Another study of corridors for several cities in Iowa (*Iowa State University 1997*) found that the installation of TWLTLs reduced crashes by 70-percent.

Table 2.1: Crash Experience for TWLTLs

Location (*Study*)	Crashes			Crash Rates (per million VMT)		
	Un-divided	TWLTL	Percent Diff.	Un-divided	TWLTL	Percent Diff.
(*Busbee 1974*)	-	-	-38	-	-	-
Southeast US (Committee #10, *Southern Section ITE 1975*)	-	-	-31	-	-	-
Arizona (*Burritt and Coppula 1978*)	-	-	-36 [b]	-	-	-
Texas (*Walton, Horne, & Fung 1978*)	-	-	-33	-	-	-
Virginia (*Parker 1983*) [a]	-	-	-	6.8	6.1	-9
Illinois (*Thakkar 1984*)	824 222	558 130	-32 [b] -41 [c]	90.8 53.3	54.3 28.6	-40 [b] -46 [c]
(*Harwood & St. John 1985*) [a]	-	-	-	3.1 1.8	0.9 0.3	-73 -85
California (*Harwood 1986*) [a]	-	-	-	2.1	1.3	-38
Michigan (*Harwood 1986*) [a]				1.8	1.9	6
N.A. (*ITE 1986*)	2,479	1,788	-28	-	-	-36
Toronto (*Kuhlmann 1987*)	-	-	-	-	-	-21
Illinois (*Box 1989*)	174	104	-40	-	-	-
Florida (*Long, Gan, & Morrison 1993*)[a]	-	-	-	4.4	3.2	-28
Arizona, California, & Georgia (*Bowman & Vecellio 1994a*)[a]	2,751 4,487	2,181 15,110	-21 [d] 237 [e]	9.9 4.2	5.6 6.9	-44 [d] 63 [e]

[a] Based on Comparison Sites (not Before-After)
[b] Five-lane sections
[c] Three-lane sections
[d] Central Business District Arterials only
[e] Suburban Arterials only

Source: Adapted from NCHRP Report 420, Table 51 (Gluck, Levinson, & Stover 1999)

In 2000, Stover and Koepke conducted a study on various safety and operational aspects of access management. They concluded that the addition of a TWLTL could result in a 35-percent reduction in total crashes.

2.1.2 Safety Effectiveness of Non-Traversable Medians

The installation of a raised or non-traversable median can enhance access management by reducing the number of conflicts at driveway locations. This enhancement results in improved traffic flow and an overall reduction in crashes. Non-traversable medians physically separate opposing vehicles and thereby restrict left-turning movements at mid-block locations. Many researchers have determined that divided highways with non-traversable medians have fewer crashes than those on similar undivided highways. Table 2.2 depicts a summary of studies included in NCHRP Report 420 (*Gluck, Levinson, & Stover 1999*) that spanned the years from 1983 to 1995 and contrasts the safety benefits of undivided roads to similar roads with raised medians.

As shown in Table 2.2, installing a raised median will generally result in a reduction in crashes (ranging from 7-percent up to 66-percent); however, the same study by Bowman and Vicellio

(*1994a*), as noted for the TWLTL, again indicated a reverse safety trend with a substantial increase in suburban arterial crashes. Crash rates decreased for all the cited studies.

Table 2.2: Crash Experience for Raised Medians

Location (*Study*)	**Crashes**			**Crash Rates (per million VMT)**		
	Un-divided	Raised Median	Percent Diff.	Un-divided	Raised Median	Percent Diff.
Virginia (*Parker 1983*)	-	-	-	6.8	4.4	-35
Texas (*City of Arlington 1983*)	-	-	-66	-	-	-
New York State (*NYDOT 1984*) [a]	-	-	-	11.3	7.4	-34
Rhode Island (*Murthy 1992*)	31	29	-7	1.1	0.9	-15
Florida (*Long, Gan, & Morrison 1993*) [a]	-	-	-	4.4	2.1	-53
Arizona, California, & Georgia (*Bowman & Vecellio 1994a*) [a]	2,751 4,487	1,714 7,663	-38 [b] 71 [c]	9.9 4.2	6.4 3.8	-35 [b] -10 [c]
California (*Harwood, et al. 1995*)						
Urban	-	-	-	3.6	2.6	-28
Rural	-	-	-	2.1	1.2	-46
Minnesota – Rural (*Harwood, et al. 1995*)	-	-	-	7.1	2.3	-67
Utah – Rural (*Harwood, et al. 1995*)	-	-	-	2.3	2.2	-2

[a] Based on Comparison Sites (not Before-After)
[b] Central Business District streets only
[c] Suburban Arterials

Source: Adapted from NCHRP Report 420, Table 53 (Gluck, Levinson, & Stover 1999)

Stover and Koepke (*2000*) conducted a study summarizing the findings of the effectiveness of access management on roadway safety and operational performance. They determined that adding a non-traversable median could reduce crashes by more than 35-percent.

Schultz, Lewis, and Boschert (*2006*) performed a study to evaluate the impacts of access management techniques in Utah. They evaluated a sample of corridors with various access management techniques (six test corridors and five control corridors). Redwood Road, for example, had a raised median installed in 1994. They compared crash data from 1992 to 1993 with similar crash data from 1995 to 1997. The average annual daily traffic (AADT) increased 12-percent during the study period. After the raised median installation, the crash rate (crashes per million vehicle miles traveled (VMT)) dropped from 8.36 to 7.25, with a decrease of access points per mile from 37.0 to 27.4.

2.1.3 Comparison of Median Treatments

While installing TWLTLs or non-traversable medians are shown to improve safety at a corridor, operational differences between these median configurations can directly affect their safety performance. For example, a TWLTL continues to permit mid-block left-turns while a non-traversable median restricts this movement. Conflicts between the turning movements at TWLTLs can increase as the number of opposing vehicles increases. As a result, many previous studies have incorporated a direct comparison between TWLTLs and raised medians with a focus on the interaction of vehicles as well as pedestrian-vehicle interactions. The following sections further explore these safety comparisons.

2.1.3.1 Safety Differences for TWLTLs versus Non-Traversable Medians

Studies since the 1980s have continuously indicated that non-traversable medians have greater safety benefits than TWLTLs; however, these non-traversable medians also can restrict local access. Table 2.3 shows a summary of studies as presented in NCHRP Report 420 (*Gluck, Levinson, & Stover 1999*) that contrast the safety of a TWLTL to that of a non-traversable median.

Table 2.3: Safety Synthesis for TWLTLs versus Non-traversable Medians

Location (*Study*)	**Crashes**			**Crash Rates (per million VMT)**		
	TWLTL	Raised Median	Percent Diff.	TWLTL	Raised Median	Percent Diff.
Virginia (*Parker 1983*) [a]	-	-	-	6.1	4.4	-28
Michigan (*Benac 1988*) [a]	-	-	-	9.6 11.1	4.1 5.6	-57 [d] -49 [e]
Arizona (*Hartman & Spalett 1989*) [a] Phoenix Tucson	- -	- -	- -	5.9 5.2	5.7 4.0	-3 -22
Georgia (*Squires & Parsonson 1989*) [a]	-	-	-	9.0 10.8	7.7 8.2	-15 [d] -25 [e]
Georgia (*Bretherton, et al. 1990; Gwinnett County 1990*) [a]	391	385	-2	8.1	6.5	-20
Ontario (*Banks, et al. 1993*)	45	33	-27	5.9	3.7	-38[e]
Florida (*Long, Gan, & Morrison 1993*) [a]	-	-	-	3.2 4.3	2.1 3.2	-35 [d] -25 [e]
Arizona, California, & Georgia (*Bowman & Vecellio 1994a*) [a]	2,181 15,110	1,714 7,663	-21 [b] -49 [c]	5.6 6.9	6.4 3.8	15 [b] -45 [c]
Tennessee (*Margiotta & Chatterjee 1995*) [a]	-	-	-	6.5	6.0	-8
Georgia (*Parsonson 1996*) [a] Memorial Blvd. State Routes	947 -	523 -	-45 -	11.9 6.2	7.9 3.7	-34 -41

[a] Based on Comparison Sites (not Before-After)
[b] Central Business District streets only
[c] Suburban arterials
[d] Four-lane sections
[e] Six-lane sections

Source: Adapted from NCHRP Report 420, Table 54 (Gluck, Levinson, & Stover 1999)

Table 2.3 indicates that highways with non-traversable (raised) medians experienced crash rates ranging from 2.1 up to 8.2 crashes per million VMT with an average of approximately 5.2 per million VMT. Highways with TWLTLs had crash rates from 3.2 up to 11.9 crashes per million VMT with an average crash rate of 7.3 per million VMT. These values equate to an average reduction in crash rate of approximately 27-percent.

Table 2.4 shows the percent difference for crash types that occurred mid-block for TWLTLs and raised medians. With the exception of Tennessee rear-end crashes; most of the crash types were consistently reduced. The observed improvement in safety can be generally attributed to improved traffic control provided by medians for pedestrians and motorists. As traffic demand increases, the median sites may begin to experience increased rear-end crashes at signalized locations (*Gluck, Levinson, & Stover 1999*).

Table 2.4: Percent Crash Difference for TWLTLs compared to Non-traversable Medians

Location (*Study*)	Percent Difference							
	Rear-End	Side-swipe	Right Angle	Left Turn	Head-on	Fixed Object	Pedestrian	Other
Georgia (*Bretherton, et al. 1990*)	-36	-29	-75	-42 [a]	-80	-100	-67	-38
Ontario (*Banks, et al. 1993*)	-50	-	-25	-	-	-	-	-33
Florida (*Long, Gan, & Morrison 1993*)								
Four-lane urban	-23	-38	-30	-46	-58	-	-60	-30 [b]
Six-lane urban	0	-31	-	-44	-50	-	-36	-
Arizona, California, & Georgia (*Bowman & Vecellio 1994a*)	-42	-	-45	-54	-47	-	-	-11
Tennessee (*Margiotta & Chatterjee 1995*)	15	-25	-24 [c]	-32 [d]	-35	-	-	79

[a] **All turns**

[b] Right turn
[c] Broadside and rear angle
[d] Front angle

Source: Adapted from NCHRP Report 420, Table 55 (Gluck, Levinson, & Stover 1999)

In addition to the studies summarized in Table 2.3 and Table 2.4, several other researchers have evaluated the safety benefits of TWLTLs versus non-traversable medians. Glennon, Valenta, Thorson, Azzeh, and Wilton (*1975*) performed a study and found that TWLTLs had higher crash rates than raised medians where driveway density and arterial street volumes are both high. The study also found that a raised median had better operational performance during higher traffic volume conditions.

Harwood (*1986*) found that midblock fatal and injury crashes in a corridor were approximately 38-, 34-, and 34-percent of all crashes on four-lane streets with undivided, raised-curb median, and TWLTL treatments, respectively.

A study performed by Chatterjee, Margiotta, Venigalla, and Mukherjee (*1991*) indicated that raised median segments had lower crash rates than TWLTLs. This conclusion was confirmed in a similar study by Parker (*1991*).

Research conducted for the Florida Department of Transportation (DOT) (*Transportation Engineering, Inc. 1995*) evaluated five roadway segments with median treatments in the Central Florida area. They determined that medians could greatly reduce the potential of crashes due to the reduced number of conflict points. They further indicated that roadways with continuous TWLTLs have more conflict points than those with medians.

In 1990 the Georgia DOT replaced a TWLTL with a raised median separation along 4.34 miles of Memorial Drive in Atlanta. Parsonson, Waters, and Fincher (*1993*) reported on the safety effectiveness of replacing a TWLTL with a raised median on this high-volume, six-lane arterial in Atlanta. The Memorial Drive project resulted in a reduction of 300 crashes and 150 injuries in the first year equating to a 37-percent reduction in the total crash rate and a 48-percent drop in the injury rate. Parsonson, Waters, and Fincher (*1998*) conducted continuous studies for a period spanning seven years. During these subsequent years, the percent reduction lessened but the clear safety benefits of medians remained consistent with these early findings.

A continuing study of medians by Parsonson, Waters, and Fincher (*2000*) evaluated 1995 to 1998 crash data for all the divided highways on the Georgia State Highway System. The highway sections included either TWLTLs or non-traversable raised medians. Table 2.5 summarizes their observations. They determined that sites with raised medians had a lower crash rate than those with TWLTLs. They observed raised medians had a 43-percent reduction in injury rate and a 4-percent reduction in fatality rate compared to TWLTLs. The effects of raised medians on pedestrian safety were also significant, with a reduction in the pedestrian fatality rate of 78-percent.

Table 2.5: Total Crashes, Injuries and Fatalities on Georgia's Divided Highways 1995-98

Median Type	Miles Studied	Average Vehicle per Day	Crash Rate [a]	Injury Rate [a]	Fatality Rate [a]	Pedestrian Fatalities per 100 Miles
TWLTL	839	18,500	561	269	1.66	3.13
Raised Median	1,295	13,900	310	153	1.59	0.69
		Percent Difference:	-45%	-43%	-4%	-78%

[a] Crashes per 100 million VMT

Source: (Parsonson et al., 2000)

The *Access Management Manual*, published by TRB, recommends that adding a median to a road that previously had a continuous TWLTL can reduce the crash rate by approximately 37-percent and the injury rate by approximately 48-percent (*TRB, 2003*).

Frawley (*2004*) performed a study to evaluate the safety performance of raised medians in Texas. He evaluated crash data that extended over an eight year period at several locations. The sites included crash data from before and after the installation of median treatments (see Table 2.6). He determined that medians have positive effects on the overall safety of a corridor, with crash rate reductions ranging from 18-percent up to 58-percent. He also determined that as the number of access points per mile increase, the crash rate also increases.

Table 2.6: Raised Median Comparisons

Corridor	Average Daily Traffic (ADT)	Before Median Type	Before Crash Rates [a]	After Crash Rates [a]	Difference in Crash Rates [a]	Percent Reduction
Bus SH 6	41,000	TWLTL	4.3	1.8	-2.5	-58 %
Loop 281	23,500	TWLTL	5.2	4.3	-0.9	-18 %
71st West	30,500	Undiv	3.8	2.5	-1.3	-34 %
71st WC	29,500	Undiv	3.8	1.8	-2.0	-53 %
US 385	10,600	Undiv	19.6	15.4	-4.2	-21 %
Others	30,600	Varies	7.0	4.8	-2.2	-31 %

[a] Units: Crashes per million VMT

Source: (Frawley, 2004)

2.1.3.2 Operational Effects of Medians

Several studies indicate that median treatments reduce delays. For example, Nemeth (*1978*) found that the overall benefits of a TWLTL were offset by the reduction in capacity with the elimination of a through lane. He also determined that an advantage of a TWLTL is reduced delay for left-turning vehicles. In a comparison of raised medians to TWLTLs, Walton et al. (*1979*) found that TWLTLs were effective at locations with frequent driveway openings and moderate left-turn demand, while the raised medians were more useful at locations with high left-turn demand. Meyer and Kruger (*1995*) found that a two-lane road with a raised median and companion left-turn lanes operated better than a four-lane road with no median treatment.

McCormick and Wilson (*1983*) concluded that in commercial areas, a two-lane cross section with a TWLTL would operate better than a four-lane section with no median treatment. Ballard and McCoy (*1983*) found that a directional volume of greater than 700 vehicles per hour justified a TWLTL.

Modur et al. (*1990*) determined that raised medians and TWLTLs were operationally equivalent at driveway spacing greater than 400 feet. They also indicated that for speeds that exceeded 45 mph, a raised median design was recommended.

Venigalla et al. (*1992*) used TRAF-NETSIM to simulate the performance of TWLTLs and non-traversable medians on four-lane roadways. They found that the difference in total delay between the two treatments is not apparent at low driveway density and traffic volume. However, TWLTLs contributed to less delay for through traffic and appeared to be more fuel-efficient at all levels of driveway density and traffic volume.

An Iowa corridor study (*Iowa State University 1997*) found that the installation of TWLTLs improved level of service by one full grade in some areas and increased lane capacity by 36-percent when compared to a non-median option.

Bonneson and McCoy (*1997*) estimated through and left-turn delays associated with various median alternatives. They concluded that TWLTLs and non-traversable medians reduce delays, especially when the roads experience large traffic volumes. They also noted that TWLTLs were generally associated with fewer delays than raised medians.

NCHRP Report 395 (*Bonneson and McCoy 1997*) summarizes the operational impacts of alternative median treatments as shown in Table 2.7. They indicated that, given the same base conditions, TWLTLs and raised medians have less annual delay than undivided roadways.

Table 2.7: Annual Delay to Major Street Left-Turn and Through Vehicles (hours/year)

Driveways/Mile	Undivided	TWLTL	Raised Median
	ADT = 22,500 vpd		
30	2,200	1,300	1,300
60	2,200	1,400	1,400
90	2,200	1,400	1,400
	ADT = 32,500 vpd		
30	7,100	3,000	3,100
60	7,800	3,200	3,500
90	8,000	3,200	3,400
Note: Assumes 10-percent left-turns, 1320-foot segment, and four through lanes			

Source: Adapted from NCHRP Report 395 (Bonneson and McCoy 1997)

Stover and Koepke (*2000*) conducted a study that evaluated the effectiveness of access management on roadway safety and operational performance. They determined that different access management techniques have various corridor impacts. For example, the addition of a TWLTL could result in a 30-percent decrease in delay and a 30-percent increase in capacity.

In general, the reported literature indicates that the use of any median treatment improves traffic operations. As traffic volumes or speeds increase a non-traversable median should be considered instead of a TWLTL as the raised median scenario performs better operationally under these conditions.

2.1.3.3 Combined Effects of Medians and other Factors

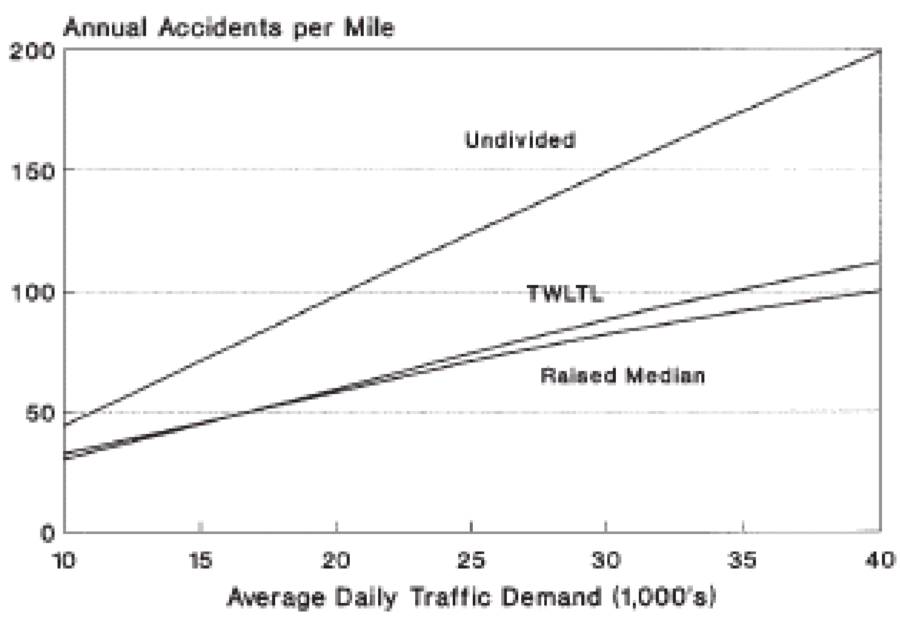
Many researchers have determined that the safety effects of medians are not independent of other physical site characteristics such as traffic volume, access/driveway density, or similar. For example, Margiotta and Chatterjee (*1995*) found that although raised medians were generally safer than TWLTLs, the TWLTLs performed better in segments with high driveway densities and low-to-medium traffic volumes. They concluded that driveway densities were an important contributor to crashes in raised median sections, but not in lower volume TWLTL sections.

Bonneson and McCoy (*1997*) analyzed three years of crash data (1991-1993) from 189 street segments located in Phoenix, Arizona and in Omaha, Nebraska. Their research indicated that crashes were more frequent on street segments with higher traffic demands, driveway densities, or intersections with public streets. They also found that an undivided roadway has a significantly higher crash frequency than the TWLTLs or raised median treatments when parallel parking is allowed on the undivided street.)

Figure 2.1, as developed by Bonneson and McCoy, shows their predicted number of annual crashes per mile based on median treatment and traffic volume. For additional information on predicted crashes for various median treatments, refer to Section 2.1.3.4. Table 2.8 shows the crash conditions based on adjacent land use and median types for the Bonneson and McCoy (*1997*) study. As shown in Table 2.8, the raised median treatment experienced the lowest crash rate (2.1), the TWLTL had a slightly higher rate (3.3), and the undivided treatment experienced the highest rate (3.8).

Gluck and Levinson (*1999*) conducted a comprehensive safety analysis using crash information obtained from Delaware, Illinois, Michigan, New Jersey, Oregon, Texas, Virginia, and Wisconsin. The researchers evaluated approximately 240 roadway segments with more than 37,500 crashes. They noted that TWLTLs generally had lower crash rates than undivided roadways, and that non-traversable medians usually had lower crash rates than all other median treatments. Overall, their study found that urban roadway segments with more than 60 access points per mile experienced approximately 2.2 times the number of crashes than roadways with less than 20 access points per mile.

Gluck, Levinson, and Stover (*1999*) noted that crashes are concentrated at intersection or crossover locations when restrictive median treatments are constructed. Table 2.9 addresses expected crash rate changes when directional and bi-directional crossovers are constructed.



Source: (Bonneson and McCoy 1997)

Figure 2.1: Predicted Average Crash Frequency Comparison

Table 2.8: Crash Frequency and Rates Categorized by Location, Land use, and Lanes

Location			Omaha			Phoenix			Total		
Median Treatment	Feature		Acc	Inj [b]	Rate [a]	Acc	Inj [b]	Rate [a]	Acc	Inj [b]	Rate [a]
Non-traversable (Raised-Curb) Median	Land use	Residential	121	53	1.7	431	197	1.3	552	250	1.4
		Office	282	105	2.3	45	10	2.6	327	115	2.4
		Business	629	265	2.5	279	121	2.4	908	386	2.5
		Industrial	18	1	0.8	0	0	-	18	1	0.8
	Thru Lanes	4	871	365	2.2	164	78	2.1	1035	443	2.2
		5	0	0	-	12	2	2.0	12	2	2.0
		6	179	59	2.8	579	248	1.7	758	307	1.8
	Total:		1050	424	2.3	755	328	1.9	1805	752	2.1
TWLTL Present	Land use	Residential	321	136	3.2	643	369	2.2	964	505	2.7
		Office	0	0	-	282	122	3.2	282	122	3.2
		Business	530	214	4.3	969	466	3.8	1499	680	4.1
		Industrial	0	0	-	17	3	1.1	17	3	1.1
	Thru Lanes	4	851	350	3.8	200	124	3.8	1051	474	3.8
		5	0	0	-	1684	824	2.9	1684	824	2.9
		6	0	0	-	27	12	1.9	27	12	1.9
	Total:		851	350	3.8	1911	960	3.0	2762	1310	3.3
Undivided Roadway	Land use	Residential	654	303	3.0	439	212	1.6	1093	515	2.2
		Office	12	2	6.7	46	13	10.3	58	15	9.9
		Business	421	176	5.5	252	158	4.9	673	334	5.3
	Thru Lanes	2	0	0	-	50	15	1.5	50	15	1.5
		4	1087	481	4.0	687	368	4.3	1774	849	4.1
	Parking	No	652	302	3.5	513	239	1.7	1165	541	2.4
		Yes	435	179	4.9	224	144	10.5	659	323	7.7
	Total:		1087	481	4.0	737	383	3.7	1824	864	3.8

[a] Segment crash rate in annual mid-signal crashes per MVT (excludes all crashes on cross street intersection approaches)
[b] Number of injuries and fatalities for all crashes.

Source: Adapted from NCHRP Report 395, Table 4-13 (Bonneson and McCoy 1997)

Table 2.9: Difference in Crash Rate between Bi-directional and Directional Crossover

Location	Treatment	Percent Difference in Crash Rate
Grand River Blvd Detroit, Michigan	Bi-directional crossover replaced by directional crossover	-61%
Michigan	Bi-directional crossover replaced by directional crossover	-15%
Michigan	Bi-directional crossover replaced by directional crossover on unsignalized roadway segment / signalized intersections	+14% -36% to 52%
Michigan	TWLTL replaced by directional crossover	-50%

Source: NCHRP Report 420 (Gluck, Levinson, & Stover 1999)

2.1.3.4 Safety Prediction Models

In addition to observing trends in the safety performance of medians, many researchers have developed predictive models so as to estimate expected safety at similar locations. Squires and Parsonson (*1989*) used a comparative study of crash rates between TWLTLs and raised medians to develop crash prediction equations. Through regression, their team determined that overall raised medians had lower crash rates than TWLTLs. A study of crash data in California and Michigan (*Harwood 1986*) supported the above claim for four-lane sections in commercial areas; however, they found that in residential areas divided cross sections had the highest crash rates.

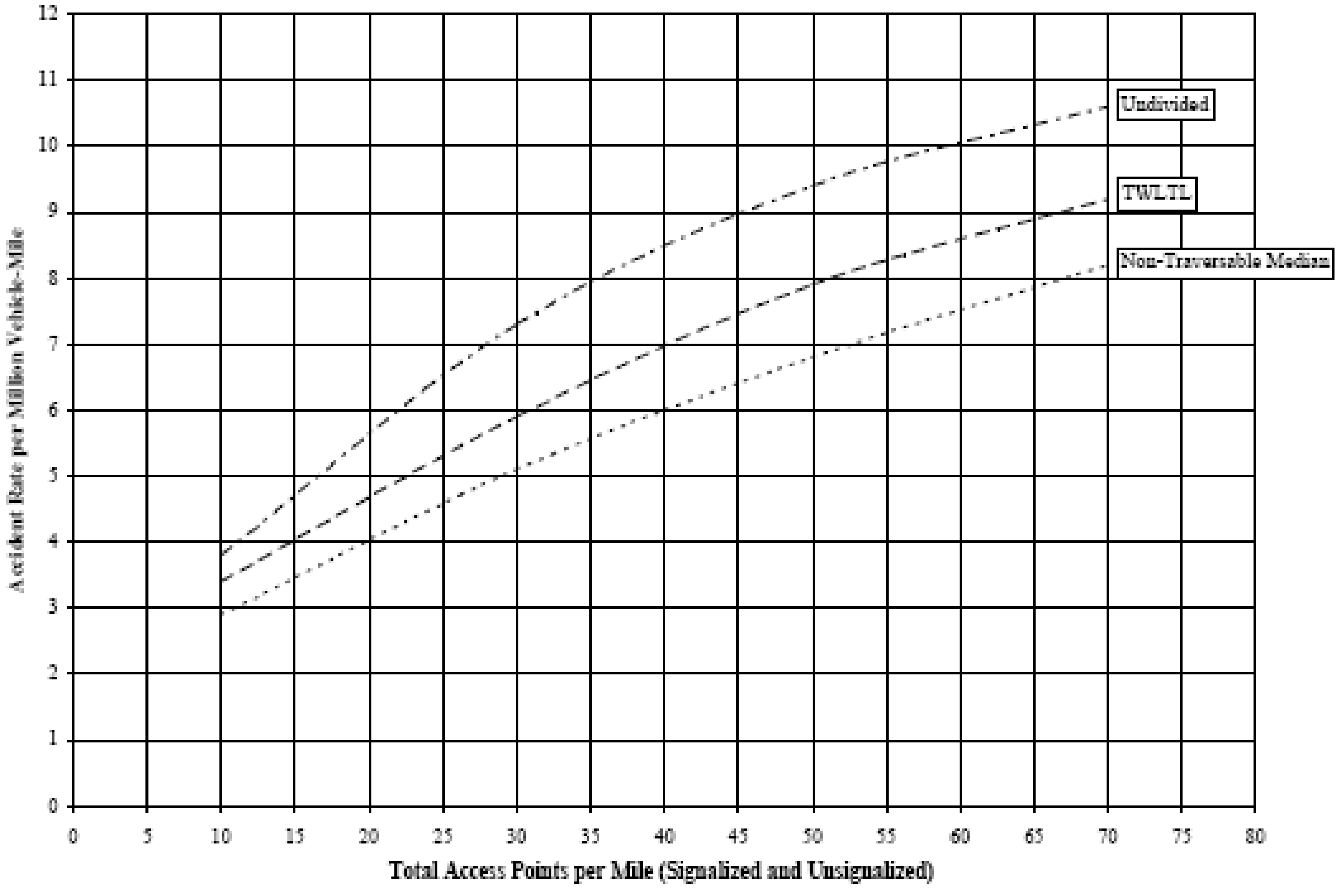
NCHRP Report 420 (*Gluck, Levinson, & Stover 1999*) included a summary for a variety of expected crashes per mile per year as predicted for a range of traffic volumes (ADT) and median treatments. These values are depicted in Table 2.10. These predictive models generally show that undivided highways have the highest expected crash rates and the installation of TWLTLs or non-traversable medians can reduce the rates by 30-percent to 35-percent. With the exception of the Harwood model, the raised median models generally produce the lowest expected number of crashes.

Table 2.10: Comparison of Safety Model Results

	Expected Crashes/Mile/Year											
ADT:	**10,000**			**20,000**			**30,000**			**40,000**		
Left-Turn treatment:	Un-divided	TWLTL	Raised Median	Un-divided	TWLTL	Raised Median	Un-divided	TWLTL	Raised Median	Un-divided	TWLTL	Raised Median
Walton, et al. (*1979*)	na	37	na	na	58	na	na	78	na	na	98	na
Harwood (*1986*)	36	27	36	72	54	72	109	81	108	145	108	144
McCoy & Ballard (*1986*)	33	31	na	oor	52	na	oor	oor	na	oor	oor	na
Squires & Parsonson (*1989*)	na	ne	37	na	31	56	na	69	75	na	108	94
Parker (*1991*)	na	27	18	na	43	32	na	58	45	na	73	59
Chatterjee, et al. (*1991*)	na	55	46	na	90	81	na	125	116	na	oor	oor
Bowman & Vecellio (*1994b*)	63	43	25	126	85	50	190	128	75	253	170	101
Average Freq.	44	37	32	99	59	58	149	90	84	199	111	100
Std.Deviation	16	11	11	38	21	19	57	39	29	76	36	35
Coeff. of Variation (%)	36	30	34	38	36	33	38	43	35	38	32	35
Excluding Harwood Data												
Average Freq.	48	39	32	126	60	55	190	91	78	253	112	85
Std.Deviation	21	11	12	-	23	20	-	33	29	na	41	23
Coeff. of Variation (%)	44	28	38	na	38	36	-	36	37	na	37	27

na = Model not available or developed for this mid-block left-turn treatment type
oor = Traffic demand exceeds range of data used to calibrate the model
ne = Model yields negative results

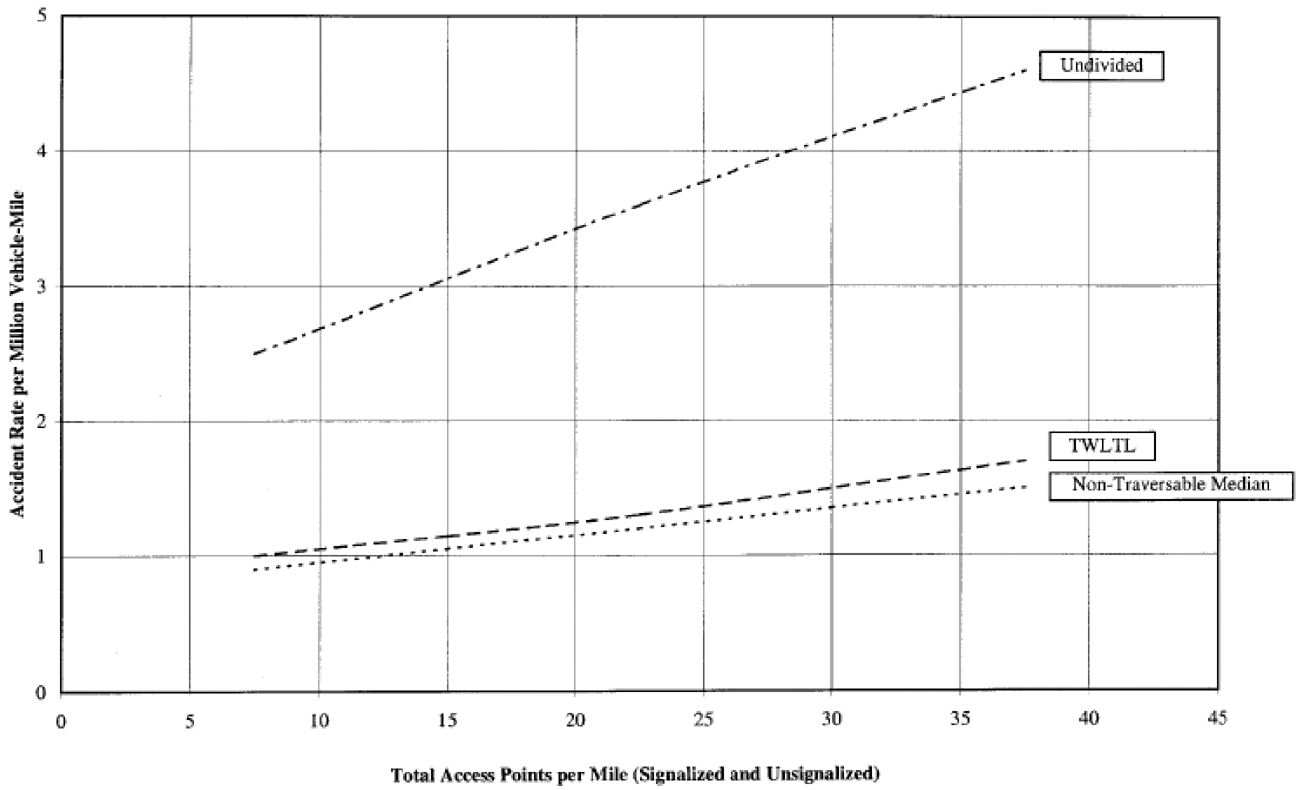
Source: Adapted from NCHRP Report 420, Table 57 (Gluck, Levinson, & Stover 1999)



Source: NCHRP Report 420 (Gluck, Levinson, & Stover 1999)

Figure 2.2: Estimated Crash Rates by Type for Median (Urban and Suburban Areas)

NCHRP Report 420 provided two figures to generally illustrate the expected relationship between access density and crash rate (*Gluck, Levinson, & Stover 1999*). Figure 2.2 shows predicted crash rates by median type and total access density for urban and suburban roadways. Each access point would increase the annual crash rate by about 0.11 to 0.18 crashes per million VMT on undivided highways and by 0.09 to 0.13 on highways with TWLTLs or non-traversable medians.



Source: NCHRP Report 420 (Gluck, Levinson, & Stover 1999)

Figure 2.3: Estimated Crash Rates by Type for Median (Rural Facilities)

Figure 2.3 shows estimated crash rates by type of median for rural facilities. Each access point is expected to increase the annual crash rate by 0.07 crashes per million VMT on undivided highways, and 0.02 crashes per million VMT on highways with TWLTLs or non-traversable medians. Table 2.11 and Table 2.12 each shows representative crash rates by median type in rural and urban areas.

Table 2.11: Crash Rates (per Million VMT) by Median Type (Urban and Suburban Areas)

Total Access Points Per Mile	**Median Type**		
	Undivided	**TWLTL**	**Non-Traversable Median**
≤ 20	3.8	3.4	2.9
20.01-40	7.3	5.9	5.1
40.01-60	9.4	7.9	6.8
> 60	10.6	9.2	8.2
All	9.0	6.9	5.6

Source: NCHRP Report 420 (Gluck, Levinson, & Stover 1999)

Table 2.12: Crash Rates (per Million VMT) by Type of Median (Rural Areas)

Total Access Points Per Mile	Median Type (crashes per million VMT)		
	Undivided	TWLTL	Non Traversable Median
≤ 15	2.5	1.0	0.9
> 15 to 30	3.6	1.3	1.2
≥ 30	4.6	1.7	1.5
All	3.0	1.4	1.2

Source: NCHRP Report 420 (Gluck, Levinson, & Stover 1999)

From Table 2.11 it can be determined that, in urban areas, undivided highways had 9.0 crashes per million VMT, compared with 6.9 for TWLTL and 5.6 for non-traversable medians. In rural areas, the undivided median still experienced the highest crash rates with an average value of 3.0 (see Table 2.12).

2.1.3.5 Pedestrian-Vehicle Interactions

A frequently cited benefit of raised medians is that, when constructed an appropriate width, the medians can facilitate pedestrian crossing by reducing the pedestrian crossing distance and, when needed, acting as a refuge location for stranded pedestrians. For example, Parker (*1983*) conducted a study of pedestrian crashes and found that raised medians are associated with about one-half as many pedestrian crashes as are TWLTLs.

A study sponsored by FHWA (*Bowman and Vecellio 1994a*) investigated the safety effect of raised medians, TWLTLs, and undivided cross sections for vehicles and pedestrians on arterial streets in Atlanta, Georgia; Phoenix, Arizona; and Los Angeles and Pasadena, California. The study locations were metropolitan area roads with unrestricted access. Bowman and Vecellio found that arterials with medians in suburban areas or downtown areas had lower pedestrian crash rates and injury crash rates than roads with TWLTLs or undivided sections.

A study performed by Long, Gan, and Morrison (*1993*) arrived at a similar conclusion (see Table 2.13). The crash rates at intersections and mid-block locations for undivided streets and TWLTLs were higher than those with a raised median.

Table 2.13: Rates for Crashes Involving Pedestrians on Urban Arterials in Florida

Median Type	Four-Lane Highway Crashes [a]		Six-Lane Highway Crashes [a]	
	Total	Midblock	Total	Midblock
Undivided	18	11	NA	NA
TWLTL	10	6	11	7
Flush Paved	9	4	12	8
Flush Grass	3	2	5	4
Raised	4	2	8	4

[a] Crashes per 100 million VMT

Source: (Long, Gan, & Morrison 1993)

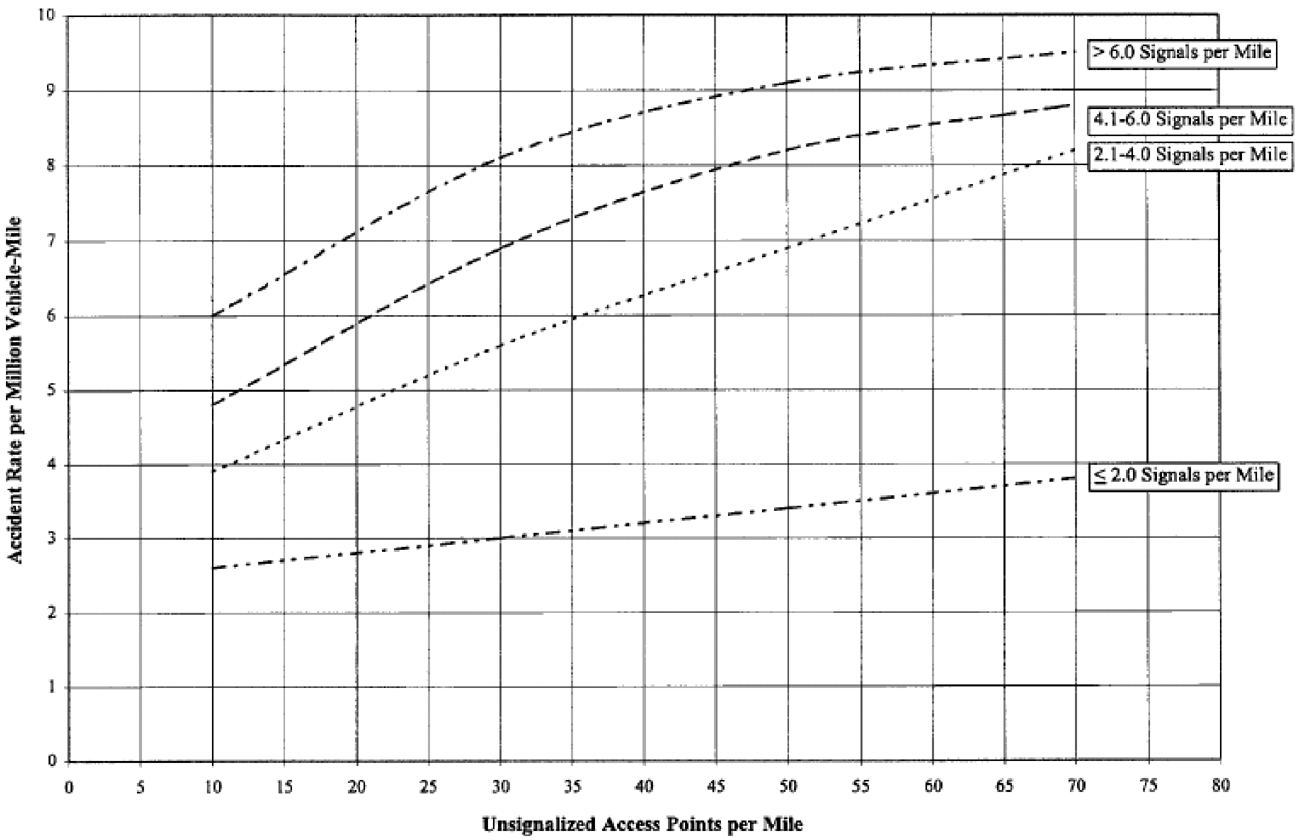
2.2 SIGNALIZED INTERSECTION SPACING

The strategic spacing of signalized intersections can facilitate access management. Closely spaced signalized intersections may have overlapping influence areas so that safe driveway placement is not practical. Similarly, signalized intersections spaced far apart can potentially reduce delay and permit driveway placement, but a substantial distance between signalized intersections may also contribute to higher operating speeds and more severe crashes. As a result, signalized intersection spacing can directly influence corridor safety and operations as reviewed in the following sections of this report.

2.2.1 Safety Effectiveness of Signalized Intersection Spacing

The safety impacts of signalized intersection spacing have been studied since the 1950s. Studies conducted in Oregon (*Head 1959*) indicated that crashes increase as driveways, intersections, and traffic signal density increase. Head further determined that the number of signalized intersections per mile most directly contributed to the number of crashes. Cribbins, Horn, Beeson, and Taylor (*1967*) also found that crash rates increased as the number of intersections per mile increased.

Squires and Parsonson (*1989*) similarly found that crash rates in Georgia increased as the number of signals per mile increased. They determined that crash rates increased by 40-percent when traffic signal density increased from two to four signals per mile. They noted, however, that the rates varied by other variables such as roadway width and type of median. A study conducted by Millard (*1993*) also evaluated the relationship between signals per mile and crashes per million vehicles traveled. Millard studied the effects of traffic signal density on crash rates in Lee County, Florida and found that the crash rate increased 2.5 times when the number of signalized intersections increased from two to four per mile.



Source: NCHRP Report 420, Figure 26 (Gluck, Levinson, & Stover 1999)

Figure 2.4: Urban and Suburban Area Access Density versus Average Crash Rates

NCHRP Report 420 included a figure (see Figure 2.4) that illustrates the relationship between signal spacing density and crash rates (*Gluck, Levinson, and Stover* 1999). Figure 2.4 shows a relationship between signals per mile, unsignalized access points per mile, and crash rate. For example, a location with 20 unsignalized access points per mile and 4.1-6.0 signals per mile results in approximately 5.9 crashes per million vehicle miles traveled. A site with a similar number of unsignalized access points but less than 2.0 signals per mile would result in approximately 2.8 crashes per million vehicle miles travelled. As expected, the higher signalized intersection density results in a much greater crash rate. Figure 2.4 also indicates that as unsignalized access points per mile increase, crash rates also increase for all signal density configurations.

2.2.2 Operational Effectiveness of Signalized Intersection Spacing

The spacing of traffic signals (frequency and uniformity) is a critical access management technique. Traffic signals directly influence delay and may constrain capacity during peak hours. Poorly spaced signalized intersections can directly influence operating speeds and general traffic operation for the corridor and associated driveways.

The influence of signalized intersection spacing on operating speeds and travel time has been studied for many years. A study of 77 streets in New York State by Guinn (*1967*), for example, determined that the traffic signal density and associated traffic volume contributed significantly to the overall traffic flow for arterial roadways. Stover et al. (*1970*) also found that total user costs decreased and traffic volume increased as signal spacing increased.

Researchers at the University of Texas (*William 1990; Kruger et al. 1991*) conducted a study to determine the relationship between average speeds and signal spacing. They determined that signal spacing is the principal influencing factor on speeds at low volumes. For high traffic conditions, however, the volume-to-capacity ratio became more important. A 1992 study by Ewing (*1992*) for Seminole County, Florida confirmed these findings and suggested that when traffic signal density and peak-hour traffic volumes increased, peak-hour travel speeds decreased. Margiotta et al. (*1993*) used NETSIM to evaluate the effects of traffic signal density and volume-to-capacity ratios on average travel speeds. Their simulation also indicated that travel speed dropped as signal density increased.

Pant et al. (*1998*) studied an intersection in Cincinnati where the local jurisdiction added a traffic signal and found a 20-percent increase in peak travel times. As part of the Colorado DOT Access Control Demonstration project (*Colorado DOT 1985*), the Colorado DOT used TRANSYT-7F to compare the operation of a 5-mile segment of roadway with and without access control. The simulated access controlled segment included one-half mile signal spacing and a non-traversable median, while the uncontrolled segment had one-quarter mile signal spacing and full median openings. The study concluded that the access controlled segment experienced a 42-percent lower total travel time and a 59-percent lower total delay during congested conditions when contrasted to the uncontrolled segment.

Gluck, Levinson, and Stover (*1999*) indicated that adding one traffic signal per mile will reduce speed by about 2 to 3 mph. Table 2.14 demonstrates the expected travel time increases based on traffic signal density. As shown, for each additional traffic signal over two per mile (i.e., one-half mile signal spacing) the travel time increased by over 6-percent.

Table 2.14: Percentage Increases in Travel Times as Signal Density Increases

Signals Per Mile	Percent Increase in Travel Times (Two Signals Per Mile as Base)
2.0	0
3.0	9
4.0	16
5.0	23
6.0	29
7.0	34
8.0	39

Source: NCHRP Report 420 (Gluck, Levinson, & Stover 1999)

The Minnesota DOT (*SRF Consulting Group Inc., 2002*) selected two theoretical corridors and used Synchro and SimTraffic to simulate the operational conditions of the corridors for various signal alternatives. They concluded that one-half mile intersection spacing in urban areas is the optimal choice for signal spacing because this configuration experienced the minimum travel time (61.8 minutes) and the highest speed (63.1 mph) for their simulated corridors.

2.3 UNSIGNALIZED INTERSECTION AND DRIVEWAY SPACING AND PLACEMENT

Unsignalized access points can include driveways as well as street intersections. Dense placement of these access points can increase conflicts between turning and through vehicles and will introduce delay to the traffic stream due to this potential disruption of traffic. Modified spacing of unsignalized intersections and driveways, therefore, is a common access management strategy. In addition, the placement of driveways too close to the influence area of an intersection can further complicate traffic operations and safety. The following sections of this report, therefore, address the safety and operational aspects of these access points as well as driveway placement near intersections (also known as corner clearance).

2.3.1 Safety Effectiveness of Unsignalized Intersections and Driveways

For over 40 years, researchers have evaluated the relationship between access management and safety. Many studies have shown that reducing the frequency of access points can improve traffic flow conditions while enhancing roadway safety. In the published literature, however, researchers have varied the definition of *access points*. While many of the published studies focused on the evaluation of the spacing of driveways, a larger body of literature included driveways and unsignalized intersections in their access point spacing definition. As a result, in this summary the use of the term *driveway* will refer simply to driveway locations while the use of the term *access points* refers to unsignalized intersections, including driveways. Frequent access points may contribute to conflicts between vehicles thereby influencing the safety performance of the road. In general, an increase in the spacing of access points reduces the likelihood of crashes by providing enough distance for drivers to anticipate potential conflicts and to recover from turning movements.

The report "Access Management for Streets and Highways" (*Flora & Keitt 1982*) documented numerous studies that verified that restricting driveway access could greatly reduce crashes. A study in Lee County, Florida (*Millard 1993*) found that crash rates double as the connections increase from 20 to 40 access points per mile.

The Federal Highway Administration (FHWA) synthesis on safety effectiveness of access control (*Cirillo 1992*) found that crash and fatality rates on corridors with full access control are one-half of those at locations with no access control and one-third of those for urban highways of similar design. Based on a series of studies in North Carolina, they also found that crashes had a close relationship with median openings and traffic volume.

In a project sponsored by the Oregon Department of Transportation (ODOT), researchers at Portland State University conducted a comprehensive crash analysis of a 29-mile Oregon Coast Highway (US Route 101) (*Lall,1995; Lall, Huntington, and Eghtedan 1996*). The crash data included 750 crashes occurring from 1990 to 1994. They found that crash frequency increased with an increase in the density of access points. The only exception to this observation occurred in a section of road with a non-traversable median.

An Australian Road Research Board (ARRB) Transport research project (*McLean 1997*) determined that frequent access points increase the crash rate by 30-percent for divided urban arterial roads and 70-percent for undivided locations. In rural areas, each minor intersection will increase the crash rate by 0.25-0.35 crashes per million vehicles and each additional private driveway per kilometer increases crash rates by 1.5 to 2.5-percent.

A study performed for the Minnesota DOT (*Preston, Keltner, Newton, and Albrecht 1998*) evaluated the relationship between access points and crash rates. They collected crash data for 4,645 segments and 10,868 miles of conventional roads and expressways. They concluded that overall, roadways with more access points have more crashes.

NCHRP Report 420 summarized a comprehensive study of the analysis of 37,500 crashes from Delaware, Illinois, Michigan, New Jersey, Oregon, Texas, Virginia, and Wisconsin (*Gluck, Levinson, and Stover 1999*). The crashes represented a variety of unsignalized access configurations and contrasted them to signalized access points. Table 2.15 shows these representative crash rates by access density for urban and suburban areas.

Table 2.15: Estimated Crash Rates by Access Density (Urban and Suburban Areas)

Unsignalized Access Points Per Mile	Signalized Access Points Per Mile			
	≤ 2	2.01-4.00	4.01-6.00	> 6
≤ 20	2.6	3.9	4.8	6.0
20.01-40	3.0	5.6	6.9	8.1
40.01-60	3.4	6.9	8.2	9.1
> 60	3.8	8.2	8.7	9.5
All	3.1	6.5	7.5	8.9

Note: Crash rates have units crashes per million vehicle miles

Source: Adapted from NCHRP Report 420 (Gluck, Levinson, & Stover 1999)

Using five years of crash data, Brown and Tarko (*1999*) developed a regression model to evaluate the relationship between access points and crash rates. They selected a large range of multi-lane road sections in Indiana with different geometric locations and access control levels. They concluded that the total number of crashes, property damage only crashes, and fatal crashes all have the same relationship with the access density: the number of crashes increases as the access density and proportion of signalized access points also increase.

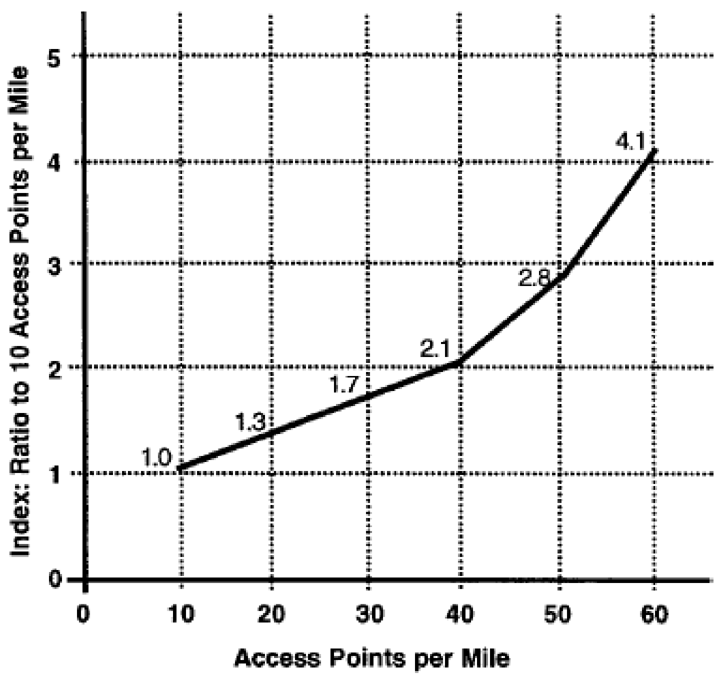
NCHRP Report 420 (*Gluck, Levinson, and Stover 1999*) also demonstrated that average crash rates increase as the number of unsignalized access connections increase. Overall, they analyzed 386 roadway segments and developed a relationship between access spacing and crashes. Table 2.16 demonstrates their findings that a roadway with 60 access points per mile has a crash rate three times larger than a roadway with 10 access points per mile.

Table 2.16: Relative Crash Rates for Total Access Connection Spacing

Total Access Points Per Mile (both directions of travel)	Crash Rate Index
10	1.0
20	1.4
30	1.8
40	2.1
50	2.5
60	3.0
70	3.5

Source: Adapted from NCHRP Report 420, Table 4 (Gluck, Levinson, & Stover 1999)

Gluck, Levinson, and Stover (*1999*) developed the graphic shown in Figure 2.5 that indicates the relationship between crash rates and access density. Figure 2.5 shows that doubling the number of access points per mile from 10 to 20 increases crash rates by 30-percent, and an increase from 20 access points per mile to 40 results in an increase in crash rates of 60-percent.



Source: NCHRP Report 420 (Gluck, Levinson, & Stover 1999)

Figure 2.5: Composite Crash Rate Indices

Levinson and Gluck (*2000*) determined that roadways with fewer access points have lower crash rates and that an increase in crash rates is directly associated with an increase in intersections and driveways.

The Kansas DOT sponsored a study (*Huffman and Poplin 2002*) to investigate the relationship between intersection density and vehicular crash rate. The study selected state highways with different configurations, such as a two-lane highway versus a four-lane highway; divided versus undivided; and rural versus urban, and analyzed crash data for a five-year period. They found the relationship between intersection density and crash rate to be linearly positive for all road type classifications.

2.3.2 Operational Effectiveness of Unsignalized Intersections and Driveways

Common traffic operations performance measures can include travel time, delay, and operating or free-flow speed. In the past, researchers have focuses on these various metrics when assessing the operational impact of access management strategies. Due to the ease of measuring or estimating speed, the most frequently estimated performance measure for operational effectiveness of access points is free-flow speed.

The *Highway Capacity Manual* (HCM) (*TRB 2000*) addresses the impacts of access density by identifying free-flow speed reduction based on the number of adjacent access points. For every 10 access points per mile, the HCM proposes a 2.5 mph reduction in free-flow speed for two-lane and multi-lane highways as shown in Table 2.17.

Table 2.17: Access Point Density Adjustment Factors

Access Points Per Mile	Reduction in Free-flow Speed (mph)
0	0.0
10	2.5
20	5.0
30	7.5
≥ 40	10

Source: Adapted from HCM Exhibits 20-6 and 21-7 (TRB, 2000)

Several studies have further documented that increasing the number of access points or reducing the access spacing along the highway would reduce travel speed and cause delay. Example studies include those conducted by Reilly et al. (*1989*) and McShane (*1996*). In these two studies, the researchers identified a decrease of 1 to 2 mph in speeds at locations with up to four driveways per mile.

Gluck, Levinson, and Stover (1999) studied curb-lane effects on through traffic by evaluating right-turn vehicles at 22 unsignalized locations in Connecticut, Illinois, New Jersey, and New York. They determined that as right-turn volumes increased, the number of through vehicles located in the curb lane that were affected by turning vehicles also increased (see Table 2.18).

Table 2.18: Percentage of Through Vehicles Affected at a Single Driveway as Right-Turn Volume Increases

Right-Turn Volume Entering Driveway (vehicles per hour)	Percent of Through Vehicles Affected
≤ 30	2.4%
31 to 60	7.5%
61 to 90	12.2%
> 90	21.8%

Source: NCHRP Report 420 (Gluck, Levinson, & Stover, 1999)

2.3.3 Corner Clearance for Driveway Placement

Corner clearance is the minimum distance between the extended curb line at an intersection and the edge of the nearest driveway. Inadequate corner clearance can contribute to operational and safety problems. A study conducted by McCoy and Heimann (*1990*) estimated the impacts of corner clearances on traffic flow. The research analyzed two signalized intersections in Lincoln, Nebraska and found that the saturation flow rate was reduced based on smaller corner clearances and associated factors. Long and Gan (*1993*) developed a model to determine an optimal corner clearance. Kaub (*1994*) developed another model based on perception-reaction time and vehicle dynamics. Values for recommended corner clearance, as depicted in the *Access Management Manual* (*TRB 2003*), are based on placement of driveways upstream of the intersection functional distance (this is the influence area of the intersection where approaching vehicles decelerate and queue). These values vary based on approach speed and lane configurations.

2.4 AUXILIARY (LEFT-TURN AND RIGHT-TURN) LANE INSTALLATION

Access management literature often includes the recommendations of adding turning lanes or bays as a strategy for enhancing safety and operations by relocating turning vehicles out of the path of through vehicles. In addition to turn lanes at median crossovers, there is a need for both left-turn and right-turn auxiliary lanes at signalized and unsignalized locations. Published research on the safety and operational aspects of auxiliary lanes is limited for right-turn lanes or bays, but there is considerable information available for left-turn lanes. As a result, the following sections highlight left-turn lane installations. Many of the observations associated with the left-turn lanes or bays can be inferred to apply similarly to the right-turn scenario

2.4.1 Safety Effectiveness of Left-Turn Lane Installation

Left turns can contribute to congestion and delay and typically require more complex multi-phase traffic signal timing at locations with high turning volumes. One common method for addressing left turns, particularly at intersection locations, is to provide exclusive left-turn lanes. In the early 1960s, Thomas (*1966*) performed a naïve before-after study in Denver and determined that the installation of targeted left-turn lanes resulted in a 6-percent reduction in left-turn crashes. An alternative method for accommodating left turns is to include shared lanes that are occupied by left-turning vehicles as well as through vehicles. Levinson (*1989*) found that for any given traffic cycle, the presence of five or more left turns in a shared lane will preempt the safe practical use of that lane. Stover and Koepke (*2000*), for example, found that adding a left-turn lane could reduce crashes by 25- to 50-percent on four-lane roads.

Since the 1960s, many researchers and engineers have conducted assessments to evaluate the safety and operational benefits of left-turn lanes. Table 2.19 shows findings from previous research that demonstrates the safety benefits for left-turn lanes. In some cases, the researchers evaluated crashes-only and at other locations they focused only on crash rates. For both metrics, left-turn lanes provided enhanced safety benefits. Table 2.19 shows a reduction in the crash rate that ranged from 5-percent (for all entering vehicles at an unsignalized intersection) up to as high as 77-percent (for left turning vehicles only at an unsignalized intersection). The analysis of the crash types has shown that the reduction in rear-end and left-turn related crashes is consistent, while the reduction in right-angle crash rates appears to be primarily associated with signalized intersections. Also depicted in Table 2.19 are observed reductions in crash frequencies. Similar trends in crash reduction are apparent for crash frequency with reductions ranging from as low as 10-percent for urban signalized intersections up to as high as 70-percent for urban unsignalized left-turns.

The published literature also included a variety of predictive models for crash reduction due to the addition of an exclusive left-turn lane, and the variables associated with these models performed in a manner consistent with that observed for field data as shown in Table 2.19 (*Maze, Henderson & Sankar, 1994; Vogt, 1999; Harwood, Council, Hauer, Hughes & Vogt, 2000*).

Table 2.19: Synthesis of Safety Experience for Left-turn Lanes

Location (Source)		Crash Frequency Percent Difference	Crash Rates Percent Difference
California (*Wilson, et al., 1967; Tamburri & Hammer, 1968*)			
	Unsignalized		-5
	Signalized		-18
	All locations		-35
	Painted	-32	
	Curbed	-59	
	Raised Bars	-67	
	All	-48	
Indiana (*Shaw & Michael, 1968*) [a]			-65
Ohio (*Foody & Richardson, 1973*) [a]			
	Unsignalized		-76 [b]
	Signalized		-38 [b]
Texas (*McFarland, et al., 1979*)			
	Urban Unsignalized - Curbed Median	-70	
	Urban Unsignalized – Painted Median	-15	
	Suburban Unsignalized – Curbed Median	-65	
	Suburban Unsignalized – Painted Median	-30	
	Rural Unsignalized – Curbed Median	-60	
	Rural Unsignalized – Painted	-50	
	Signalized with Exclusive Phase	-36	
	Signalized no Exclusive Phase	-15	
Israel (*Ben-Yakov & Craus, 1980; Craus & Mahelel, 1986*)			-38 [c]
Kentucky (*Agent, 1983*)			
	Unsignalized		-77 [d]
	Signalized		-54 [d]
Indiana (*Greiwe, 1986*)		-57 [e] -62 [f]	
Nebraska (*McCoy & Malone, 1989*) [a]			
	Unsignalized	-35	-51
	Signalized	-54	-56
New Jersey, Rte 47 (*NJDOT, 1992*)		-39	
New Jersey, Rte 130 (*NJDOT, 1993*)			
	Southern Section		-35
	Northern Section		-51
Illinois, Iowa, Louisiana, Minnesota, Nebraska, North Carolina, Oregon, & Virginia (*Harwood et al., 2002*) [a]			
	Urban Unsignalized Four-Leg	-27	
	Urban Unsignalized Three-Leg	-33	
	Urban Signalized Four-Leg	-10	
	Urban Newly Signalized Four-Leg	-24	
	Rural Unsignalized Four-Leg	-28	
	Rural Unsignalized Three-Leg	-44	
	Rural Newly Signalized Three-Leg	-24	

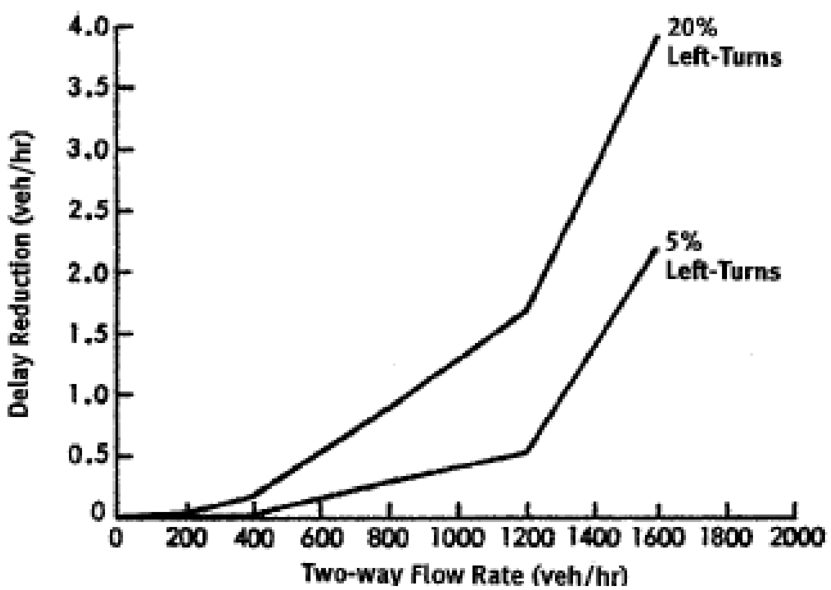
[a] Based on Comparison Sites (not Before-After)
[b] Based on units of million vehicles per leg per year
[c] Based on crashes per intersection per year
[d] Based on left turn vehicles
[e] Based on mean crashes per intersection per year
[f] Based on left-turn crashes

Source: Adapted from (Gluck, Levinson, & Stover, 1999; Harwood et al., 2002)

2.4.2 Operational Effectiveness of Left-Turn Lane Installation

In addition to safety benefits, the installation of left-turn lanes also enhances traffic operations by separating the left-turning vehicles from through traffic. Craus and Mahalel (*1986*) simulated and analyzed two-lane roads that did not have left-turn lanes. They found that the proportion of through vehicles blocked by turning vehicles was associated with the two-way traffic volume and the percentage of vehicles turning left in the same direction or travel. As the volume and the left-turn percentage increased, the proportion of blocked through vehicles similarly increased. A study conducted by Levinson (*1989*) estimated the proportion of through vehicles blocked by shared lane left-turning vehicles based on the number of left turns per cycle. He indicated that as the number of left turns per cycle increased, the proportion of blocked through vehicles similarly increased. He also noted that the capacity is diminished for exclusive through lanes when opposing left-turning vehicles are present.

Harwood and Hoban (*1997*) studied the effect of left-turn lanes in terms of reduced delay. Figure 2.6 demonstrates that constructing exclusive left-turn lanes at road segments with 20-percent left-turning vehicles results in a greater reduction in delay then would be achieved at locations with only 5-percent left-turning vehicles. Stover and Koepke (*2000*) found, for example, that adding a left-turn lane on four-lane roads could help to increase capacity by as much as 25-percent.



Source: (Harwood and Hoban, 1997)

Figure 2.6: Delay Savings of Left-Turn Lanes on Two-Lane Rural Highways

Gluck, Levinson, and Stover (*1999*) developed at table for NCHRP Report 420 based on the 1994 *Highway Capacity Manual* that includes capacity information for two-lane and four-lane roads with various left-turn treatments as shown in Table 2.20.

Table 2.20: Capacity Implications of Shared and Exclusive Left-Turn Lanes

Condition	Two-Lane Road (vphpl)	Four-Lane Road (vphpl)
No Left-Turns	840	1,600
Shared Through/Left-Turn Lane Left-Turns/Hour:		
50	650	1,000
100	500	960
150	425	900
Exclusive Left-Turn Lane		
Unsignalized	960	1,100
Left-Turn Phase	750-800	1,250-1,460

Source: (Gluck, Levinson, & Stover 1999)
Note: Computation assumes 60-90 cycle, 50 percent green plus clearance time per cycle, 3 seconds lost time, and 1,900 vehicles per hour per lane (vphpl) saturation flow.

2.5 U-TURNS AS ACCESS MANAGEMENT STRATEGIES

The use of U-turns for access management can be accommodated in several ways. One of the most common methods observed in the published literature were the restriction of left-turns at driveways followed by the use of U-turns (at the next intersection or at median crossovers) as alternatives to these direct left turns. A second common U-turn treatment is the use of directional crossovers instead of bidirectional crossovers at median locations. Both of these U-turn applications are reviewed in the following sections.

2.5.1 Safety Effectiveness of U-Turns as Alternatives to Direct Left-Turns

U-turns may be used to reduce conflicts by redirecting left turns from driveway access to intersection locations. U-turn laws vary between states. In some states like Oregon, U-turns are prohibited unless specifically indicated at intersections controlled by a traffic signal, at locations between intersections on highways within incorporated city limits, and at places without adequate visibility (refer to Oregon Illegal U-turn law *2011 ORS § 811.365*). Other states, such as California, have a very different law that permits U-turns unless directly prohibited by signage at a specific location. Because the prohibition of left-turn movements at driveways may result in increased left-turn volumes at intersections and contribute to longer left-turn phases, U-turns are commonly used to divert these left-turning vehicles at intersection or median locations.

In recent years, several researchers have evaluated the safety impacts of using U-turns as alternatives to direct left-turns. NCHRP Report 420 (*Gluck, Levinson, & Stover 1999*) synthesized research studies from the State of Florida that evaluated the safety effectiveness of U-turns (see Table 2.21).

Table 2.21: Difference in Crash Rate for Operational Configurations Enhanced with U-turns

Location	Treatment	Percent Difference in Crash Rate
US-1, Florida	Driveway left turns replaced by right-turn / U-turn	-22%
Florida	Left turns replaced by right-turn / U-turn	-18%

Source: NCHRP Report 420 (Gluck, Levinson, & Stover 1999)

Another study conducted in Florida (*Zhou et al. 2000*) studied the safety effects of replacing a direct left turn with a right turn plus median U-turns. Zhou et al. collected the data from several sites and determined that the effect of U-turns on reducing conflict rates was significant as shown in Table 2.22. The table indicates that right-turn plus U-turns experienced a conflict rate of approximately 5-percent, while direct left-turns had a much higher conflict rate of almost 26-percent.

Table 2.22: Comparison of Conflict Rates Caused by Direct Left-Turn Movements and Right-Turn plus U-turn Movements

	Right turn plus U-turns		Direct Left Turns
	Right turns	**U-turns**	
Number of Vehicles	1975	1975	1764
Number of Conflicts	56	43	457
Conflict Rates	2.84%	2.18%	25.91%
	5.02%		

Source: (Zhou et al., 2000)

Dissanayake et al. (*2002*) studied the safety performance of U-turns and found vehicles making right-turns followed by U-turns experienced 47-percent fewer conflicts than those making direct left-turns.

Another study conducted by Lu et al. (*2002*) analyzed crash data at 7 sites in the Tampa Bay, Florida area and compared the conflicts rate at two different median treatments: Direct Left Turns (DLT) and Right Turns followed by U-Turns (RTUT). The crash analysis indicated an 18-percent total crash rate reduction associated with the U-turn option and a reduction in the injury crash rate of 27-percent.

In NCHRP Report 524 (*Potts et al. 2004b*), researchers studied the safety performance of unsignalized median openings. The research results indicated that increasing U-turn volumes at unsignalized median openings can improve safety. Studies found that collisions related to U-turn and left-turn maneuvers at unsignalized median openings occur infrequently. Unsignalized median openings along arterial corridors experienced an average of 0.41 (urban) and 0.20 (rural) U-turn-plus-left-turn crashes per median opening per year. U-turns did not appear to have a negative effect on the safety performance of intersections and corridors.

In North Carolina, Carter et al. (*2005*) studied crash data at 78 signalized intersections. They found that U-turns were not involved in any crashes at the study location for 65 of the sites during the 3-year study period. The U-turn crashes at the remaining 13 sites ranged from 0.33 to 3.0 crashes per year, suggesting a minimal adverse influence on safety in the immediate region of the affected 13 signalized intersections.

Lu et al. (*2005a*) studied eight sites in Florida and compared the safety performance of right turns followed by U-turns and direct left turns. The selected corridor segments included six or more lanes. The research team acquired over 900 hours of video-based traffic data. They then analyzed the conflict rate and compared the two alternatives based on conflicts per hour and conflicts per thousand involved vehicles. The DLT movements had 6.7 conflicts per hour, while the number for vehicles making RTUT at signalized intersection was 2.4. DLT and RTUT movements experienced an average of 40.6 and 26.2 conflicts per thousand vehicles, respectively. As a result, RTUT movements generated a lower number of conflicts and reduced the potential severity of conflicts than for the DLT movements.

Lu et al. (*2005b*) also conducted a safety evaluation for 4-lane arterials. They collected data at sixteen sites: eight signalized intersections and eight median opening sites. At signalized intersection sites, the DLT movement had 200-percent more conflicts per hour than the RTUT movements. At median opening sites, the DLT movements had 10-percent more conflicts per hour than the RTUT movements.

A synthesis performed for the Federal Highway Administration (*Jagannathan, 2006*) documented the safety and operational benefits of U-turn intersection treatments. The Jagannathan (*2006*) report refers to a study of a 0.43 mile road in Wayne County, Michigan conducted by Maki (*1996*). At this location, existing conventional signalized intersections were modified to become median U-turn intersection treatments where direct left-turns were completely removed from the signalized intersection. Drivers first had to traverse through the intersection and then execute a median U-turn to complete a left-turn movement. The average crash rates for the entire corridor were reduced by approximately 14-percent. Crash rates for intersections with U-turns were 16-percent less than the conventional, with 30-percent lower injury crash rates.

Another study conducted by Liu et al. (*2008*) investigated the impacts of the separation distances between driveway exits and downstream U-turn locations on the safety performance of right-turns followed by U-turns. Liu et al. studied 140 select street segments in the State of Florida, all of which were urban or suburban arterial segments with non-traversable medians and directional median openings. At these locations, U-turns were provided at a downstream median opening or signalized intersection, and the selected street segments were straight without any on-street parking. The study crash data included 76-percent of crash data from three years (2003 to 2005) with a total of 2038 crashes. Their research team used the total crash model and a target crash model to analyze the crash data. The resulting model provided a tool to quantify the safety effects of various independent variables, and indicated that increasing access spacing by 10-percent will reduce the target crashes by 4.5-percent and total crashes by 3.3-percent.

2.5.2 Safety Effectiveness of Direction Crossovers as Alternatives to Bidirectional Crossovers

In addition to redirecting direct left-turn movements to nearby U-turns, another strategy is to restrict turning movements in the median by using directional median crossovers rather than bidirectional crossovers. The synthesis developed by Jagannathan (*2006*) reviewed a Michigan study evaluating the safety effects of U-turns versus medians for 123 segments along 226 mile of highways. Castronovo et al. (*1998*), the Michigan researchers, indicated that signalized intersections with directional U-turn median crossovers had a 50-percent lower crash rate than for conventional intersections. The observed crash rate reductions increased as the number of signalized intersections per mile also increased.

Another study performed by Scheuer and Kunde (*1996*) studied the effects of replacing bidirectional crossovers with directional crossovers. The study segment occurred at two commercialized land use locations in Wayne County, Michigan that were characterized by frequent roadway and access intersections. The research team analyzed five years of crash, with three of the years preceding the access management project. The researchers observed a total crash reduction of 24-percent with a substantial reduction in head-on and angle crashes.

Taylor et al. (*2001*) conducted a similar study on eight sections in Michigan between 1991 and 1997. Their research team investigated all the crashes associated with the study roadway segments including those that occurred at intersections. The average reduction in total crash frequency was 31-percent with a reduction of 32-percent in injury crash frequencies. The placement of directional crossovers at previously bidirectional median crossover locations for four-legged intersections resulted in a reduction in total crash frequency of 58-percent. Similarly, the use of directional crossovers at three-legged intersections resulted in total crash frequency reductions of 34-percent.

In 2001, officials in Pinellas County, Florida transformed a full median opening into a directional median opening on a six-lane highway. Lu (*2001*) performed a study to evaluate the safety performance after the change by counting the number of potential conflicts. After installing the directional median opening, the average number of daily conflicts was reduced by approximately 15-percent. The average number of conflicts per hour was also reduced by 50-percent. The conflict rate for RTUT vehicles during peak hours was 8-percent lower than during non-peak hours.

Potts et al. (*2004a*) studied crash data at 481 conventional full median openings and 187 directional median openings. They found that the median sites experienced 0.41 and 0.20 U-turn plus left-turn crashes per median opening per year respectively at urban and rural locations. The infrequent crash rate values indicated that U-turns introduce, at best, minimal harm to the safety performance of median openings.

2.5.3 Operational Effectiveness of U-Turns

The use of U-turns as an alternative to direct left-turns can directly affect roadway capacity and travel time. Several researchers have evaluated these operational influences by contrasting the use of medians plus U-turns to TWLTL operations. For example, Savage (*1974*) studied the operational behavior at five-lane roadways with a TWLTL and a U-turn in Michigan and found the U-turn and raised median configuration resulted in a 20- to 50-percent increase in the corridor capacity. A study by Stover (*1990*) computed lane volumes for the intersection of two six-lane arterials to evaluate the effects of re-routing left turns. TWLTLs on all approaches reduced lane volumes by 12-percent compared to single left-turn lanes at multi-phase signalized locations. As an alternative, 17-percent of lane volumes were reduced by the re-routing of left-turns.

Koepke and Levinson (*1993*) studied the capacity effects of U-turns, and determined that directional U-turns could result in an increase of 14- to 18-percent more capacity than for TWLTLs. They also estimated a 7 to 17-percent decrease in critical lane volumes for arterial roads. Maki (*1996*) compared U-turns to the conventional TWLTL on four-lane and six-lane boulevards and found that the use of U-turns resulted in a 20- to 50-percent increase in capacity.

Dorothy et al. (*1997*) evaluated traffic operations for U-turns compared to the conventional TWLTLs by using the micro-simulation tool TRAF-NETSIM. The simulation was based on a STOP-control when turning percentages were low and a signal control with higher volumes. Dorothy et al. found that U-turns with signalized directional crossovers had lower left-turn total travel times and lower network travel times than for conventional intersections. For low left-turning percentages, they determined that the two designs experienced similar left-turn and network total time.

A study conducted in Florida (*Zhou et al., 2000*) evaluated the operational effects of replacing direct left turns with a right turns plus median U-turns. Their research team collected data from several urban and suburban sites and determined that road segments with right turn plus U-turn treatments experienced much less average waiting delay than road segments with direct left turns. Table 2.23 depicts the average travel time and average waiting time resulting from their comparison.

Table 2.23: Average Travel Time and Average Waiting Time

	DLT	**RTUT at Full Median Opening**	**RTUT at U-Turn Median Opening**
Total conflicting volume (vph)	4600	4600	4400
(Range)	(3000-6000)	(3000-6000)	(3000-5500)
Average Left Turn (LT) volume (vph)	36	/	/
(Range)	(0-96)		
Average Right Turn (RT) volume (vph)	/	208	190
(Range)		(0-360)	(60-390)
Average U-turn (UT) volume (vph)	/	84	47
(Range)		(36-156)	(12-108)
Weaving distance (ft)	/	570	800
Average total travel time (seconds)	45	54	52
($t_1/t_2/t_3$)	(25/15/5)	(20/17/16)	(18/13/21)
Average waiting time (seconds)	40	37	31

Source: (Zhou et al., 2000)

Bared and Kaisar (*2002*) used the micro-simulation program CORSIM to examine the traffic operational performance of signalized median U-turns with a three-phase signal on four-lane roads. They incorporated a right-turn lane from the major road to the cross-street and evaluated entering volumes at the intersections ranging from 2,000 vph to 7,000 vph. Bared and Kaisar found that with 10-percent and 20-percent left-turn volumes for higher entering flows (greater than 6,000 vph), the U-turn configuration provided improved travel time when compared to conventional intersections.

Lu et al. (*2005c*) evaluated eight Tampa Bay, Florida area sites with six or more lanes and a raised median. The research team developed delay and travel time models based on field and video data. They found that when both the DLT and RTUT flow rates are approximately 50 vph, the average total *waiting delay* for the RTUT is greater than that for the DLT until the major-road through-traffic flow rate reaches 5,500 vph. Similar thresholds occurred at 5,200 and 5,000 vph, respectively, for flow rates equal to 100 vph and 150 vph. At locations where both the DLT and RTUT flow rates are equal to 50 vph, the average total *travel time* of the RTUT was greater than that of the DLT until the major-road through-traffic flow rate reaches 6,600 vph. Similar thresholds occurred at 6,000 and 5,400 vph, respectively, for flow rates equal to 100 vph and 150 vph. Additionally, the regression model developed in this study also indicated that fewer drivers would select the RTUT when the offset distance from the driveway to the downstream signalized intersection is relatively long.

Topp and Hummer (*2005*) used the micro-simulation program CORSIM to compare median crossovers at cross street locations for highways. The researchers found that the U-turn design along the cross street reduced the percentage of stopped vehicles, total travel time, and delay for most of the volume combinations when compared to the crossover configuration.

2.6 ACCESS MANAGEMENT AT ROUNDABOUTS

Roundabouts represent a potential solution for intersections that typically have numerous conflict points. Though not appropriate for all situations, roundabouts may offer potential access management benefits by providing another alternative to direct left-turn movements at intersections. A few studies have examined the safety benefits of roundabouts. Ewing (*1999*) concluded the benefits attributable to roundabouts include increased safety, increased vehicular capacity (up to 50-percent), reduced fuel consumption, improved air quality, lower cost, aesthetics, convenient U-turns, and traffic calming.

Myers (*1999*) studied four Maryland intersections that were replaced with roundabouts and identified a reduction in crashes between 18- and 29-percent with a reduction in injury crashes between 63- and 88-percent. Crash severity at roundabouts was also minor when compared to other left-turn configurations.

Another roundabout study by Jacquemart (*1998*) identified a 51-percent reduction in crashes, including a 73-percent reduction in injury crashes and a 32-percent reduction in property-damage-only crashes for single-lane roundabouts. Multi-lane roundabouts only resulted in a 29-percent reduction in crashes.

The *Roundabouts Brochure* by the USDOT (*2004*) estimates up to a 90-percent reduction in fatalities, a 76-percent reduction in injury crashes, and a 30- to 40-percent reduction in pedestrian-related crashes with the use of roundabouts. The USDOT document also estimates that roundabouts can provide a 30- to 50-percent increase in traffic capacity at an intersection with a volume increase from 800 to 1,200 vehicles per lane.

Between 1998 and 1999, the City of Golden, Colorado installed a series of four roundabouts on South Golden Road. Ariniello (*2004*) reported that, following some initial controversy, most users have grown to appreciate the roundabouts. Ariniello noted that the total crash rate reduced by approximately 88-percent during the study period of 1996 to 2004. The roundabout modifications also resulted in a decrease in average speed and travel time.

2.7 ACCESS MANAGEMENT AT INTERCHANGES

Interchanges facilitate access between freeways and arterial streets or crossroads. As a result, commercial land use development frequently occurs in the regions near interchanges. A lack of access management on crossroads in the vicinity of interchanges can result in safety and operational deficiencies. The placement of intersections and driveways in the immediate proximity of ramp termini for interchanges coupled with heavy weaving volumes can result in frequent crashes and operational constraints. One common strategy to help mitigate safety and operational problems near interchanges is to increase separation distances between intersections or driveways and interchanges.

As early as the 1960's, Netherton (*1963*) analyzed access management issues near interchanges and concluded that due to wide variations in traffic volumes and speeds near interchange locations, effective access management and land use control measures should be considered.

Layton (*1996*) developed guidelines for ODOT to address access spacing at interchanges. Table 2.24 depicts Layton's recommendations for minimum access spacing near freeway interchanges. The table indicates, for example, that the nearest major signalized intersection on both sides of the interchange should be located at least 1320 ft from the interchange.

Table 2.24: Suggested Minimum Access Spacing Standards for Two and Four-Lane Cross Routes at Freeway Interchanges, Oregon

Access Type	Area Type		
	Fully Developed Urban (45 mph)	**Suburban (45 mph)**	**Rural (55 mph)**
Two-lane Cross Roads			
First Access (ft)	750	990	1,320
First Major Signalized Intersection (ft)	1,320	1,320	1,320
Four-lane Cross Roads			
First Access from Off-Ramp (ft)	750	990	1,320
First Median Opening (ft)	990	1,320	1,320
First Access Before On-Ramp (ft)	990	1,320	1,320
First Major Signalized Intersection (ft)	2,640	2,640	2,640

Source: (Layton, 1996)

Papayannoulis et al. (*1999*) studied traffic performance near interchanges and found that increasing the spacing between intersections and access points improved traffic flow and safety. They hypothesized this improvement could be due to reducing the number of conflicts and a result of providing adequate distance to anticipate and recover from turning movements.

Williams et al. (*2004*) studied the costs and benefits of acquiring limited access at freeway interchange areas. They selected several representative interchanges in Florida and analyzed their crash data for a 5-year period. They evaluated the relationship between the length of limited access frontage and the number of crashes. Increasing the length of limited access frontage resulted in a decrease in the number of crashes, fatalities and injuries. They also evaluated traffic operations based on access spacing and found that increasing access spacing from 200 feet to 600 feet resulted in the most significant capacity gains. They noted that when the signalized access spacing was equal to 200 feet, the interchange experienced a poor operational performance.

Flintsch (*2008*) developed a program to determine the optimal limited access length as measured from the ramp terminals. He studied 186 locations (with a combined total of 2,277 crashes) and the distribution of the distance to the first access point. He determined that the longer the distance between the first access points and interchange terminals, the fewer crashes could be expected.

2.8 ACCESS MANAGEMENT ECONOMIC IMPACTS

A common concern regarding the use of access management, particularly as it relates to restrictive medians and limited driveways, is the effect such strategies will have on property values as well as business access and sales (when applicable). The literature includes several studies that assess the overall economic impacts of access management. In addition, there are several published research studies that directly consider the economic implications of median alternatives and, in one case, interchange constraints. These findings are summarized in the following sections.

2.8.1 Overview of the Economic Impacts of Access Management

Historically, the economic impacts of access management have focused on the accessibility and exposure of potential visitors to the site. Often access management is perceived to have the potential to adversely affect access to local businesses by restricting driveway frequency, configuration, or location. Business owners often express concern that access management may make access so inconvenient that potential customers will elect to go elsewhere resulting in economic hardships for the business and reduced property value. This concern has been the focus of several studies.

Vargas and Guatam (*1989*) found that more than 70-percent of the businesses impacted by an access management project in Florida reported no change in property value, while 13-percent reported some increase in property value.

To assess the level of impact of access management on local businesses, Iowa researchers conducted a comprehensive study (*Chao et al. 1998*). They evaluated sales tax data for the study areas and determined that sales along the associated corridors outpaced those of the overall community by 10- to 20-percent following the completion of adjacent access management projects. The business owner surveys further indicated that more than 85-percent of the businesses reported that their sales either remained the same or increased. Only 5-percent reported a decrease after the implementation of access management, although they did not identify any direct correlation between this decrease and the access management implementation. In general, the local businesses supported the access management projects.

The Florida DOT (*Stover 1998*) conducted a similar analysis of the impact of access management on the economic vitality in Fort Lauderdale and Orlando. Approximately 62-percent of surveyed businesses reported no changes in business sales following the retrofit of a boulevard in Fort Lauderdale. A survey conducted in Orlando also found that 80-percent of the drivers believed that the road was safer with improved traffic flow. Approximately 60-percent of the drivers, however, did indicate that required U-turns were not convenient.

A study performed by Eisele and Frawley (*1999)* determined that land values along Texas corridors with access management projects stayed the same or increased. They found very few exceptions to this observation.

A study (*Rees et al. 2000*) of Kansas properties impacted by access changes determined that the majority of adjacent business remained the same after the access management project was completed, even for the businesses that had direct access before the project and access restricted to frontage roads following project completion

Vu and Shankar (*2006*) evaluated 280 businesses along six State of Washington commercial corridors. They performed this analysis by issuing a survey to the local business. The survey focused on business use, business operation, access management, street environment, and corridor characteristics. They found that most businesses with shared driveways or with traffic signals at their driveways had a positive perception of access management, while driveways with a right-in right-out configuration were perceived by the businesses to negatively impact patronage.

Preston et al. (*2007*) performed a study of commercial property values adjacent to a major access management project in Minnesota and found that changes in access had little or no effect on property values. Local economy and the general location of the property were determined to be greater contributors to the value of properties. The impacts of access management were found to be either neutral or positive. In fact, a number of several business types increased following the project. After a comprehensive analysis of population, changes in income, types of retail businesses, and retail sales from 1980-2000, Preston et al. further evaluated land values and business productivity and determined that the impacts of access management improvement projects were either neutral or positive for all business types.

2.8.2 Economic Impacts of Median Alternatives

The economic impacts of median alternatives can be a factor of how the access to adjacent property is increased or decreased as a result of the median. One common negative perception about the installation of raised medians is that they often directly limit access to adjacent property and cause business patrons to travel longer distances. On the other hand, the use of a median may help facilitate improved capacity. This operational enhancement may result in an opportunity for more people to travel by a business establishment than prior to the median construction.

Wootan et al. (*1964*) studied the impacts of raised medians on sales volumes in Baytown, Pleasantville, and San Antonio, Texas. “Traffic serving” businesses that were not located at median openings reported a 44-percent decline in sales after median construction, while non-traffic-serving businesses reported no change.

Squires and Parsonson (*1989*) studied the economic effect of the installation of raised medians on Jimmy Carter Boulevard and Memorial Drive in Metropolitan, Atlanta. Based on business tax records from before the TWLTLs were replaced by raised medians, they found that 21 business owners reported a decrease in sales, while 15 reported an increase in sales following median construction. These results suggest that the raised median did not lead to an overall negative impact, although some mid-block businesses may have suffered more than others. Neuwirth et al. (*1993*) found that adverse impacts on local businesses could result from the installation of raised medians if the businesses are dependent on pass-by traffic (such as gas stations and fast-food restaurants).

Ivey, Harris and Walls Inc. (*1995*) performed a study to evaluate the effects of medians on business in Florida. They surveyed drivers and business operators along four state routes during 1995 and asked about their attitudes regarding the effects of restricted medians. The majority of the drivers surveyed perceived safety and traffic flow to be better following construction of the medians. More than half of the business owners reported no change or an increase in their sales after the median construction.

Plazak et al. (*1998*) conducted a study to estimate the impact of access management on business vitality. They evaluated five case studies that include raised medians, TWLTLs, and driveway consolidation. In Iowa, about half of the businesses do not renew their sales tax permits beyond five years. This is referred to as loss. In the study period, the results indicated that the business loss rates for the case study corridors were less than or equal to others in the community. Actually, at four of the five case study locations, the corridor business loss rate was 15-percent to 20-percent lower than the rate for their community.

Frawley and Eisele (*1998*) developed a methodology for estimating the economic impacts of raised medians on adjacent businesses. They conducted a case study in the State of Texas and found that the perception by business owners that their gross sales decreased following construction ranged from 16-percent to 22-percent (see Table 2.25). Most of the study corridors were undivided roadways prior to construction with raised medians added during construction.

Table 2.25: Gross Sales Perceptions of Business Owners

Construction Stage	Down (%)	No change (%)	Up (%)	Unsure
All business in northern segment, currently under construction (n=24)				
During	67	21	12	--
After	22	30	35	13
All business in southern segment, prior to construction (n=69)				
During	61	26	7	6
After	16	44	29	11

Source: (Frawley and Eisele 1998)

In a follow up study by Eisele and Frawley (*1999*) then determined that corridors with access control improvements actually experienced an 18-percent increase in property values following construction.

In *NCHRP Report 420*, Gluck, Levinson, and Stover (*1999*) included an estimate compiled from a synthesis of previous research of the expected economic impact (in terms of percent pass-by trips) at left-turn prohibited median treatments (see Table 2.26). The table summarizes the estimates of the maximum impact of the medians for typical land uses.

Table 2.26: Economic Impact Model at Median Locations

Land Use	Percent Pass-by	Estimated Left Turns As Percent of Total Entering Traffic
1. Gasoline Service Station Convenience Mart Small Retail < 50,000 sq.ft.	55	ADT % 5,000 43 10,000 40 20,000 30 30,000 15
2.Fast Food Restaurant with Drive Through Window Supermarkets Shopping Center 50,000-100,000 sq. ft.	45	Or more
3. High Turnover sit-down restaurant	40	
4. Shopping Centers 250,000-500,000 sq. ft.	30	
5. Shopping Centers Over 500,000 sq. ft.	20	

Source: NCHRP Report 420 (Gluck, Levinson, & Stover 1999)

A survey conducted by Gwynn (*2000*) found that among 230 responses, 86-percent of the business predated the construction of a median with U-turn modifications, and 64-percent responded that they did not suffer any adverse impacts as a result of the change. In fact, 57-percent of the business owners reported an increase or stability in their business volumes.

A before-and-after study for a median reconstruction project in Florida determined that 68-percent of the survey participants reported little or no economic impact to their businesses, although 27-percent reported some type of loss following the closure of select median openings (*Stover & Koepke 2000*).

2.8.3 Economic Impacts of Interchanges

Very little economic assessment of access management in the vicinity of interchanges has been included in the published literature at this time; however, one study performed by Williams et al. (*2004*) studied the costs and benefits of acquiring limited access at freeway interchange areas. They selected several representative interchanges in Florida. They performed a benefit-cost analysis for three different lengths of limited access frontage: 200 ft, 600 ft, and 1320 ft separations. The study evaluated urban or rural areas, and they determined that the 1320 ft alternative resulted in a better benefit and cost ratio when compared to the other two options.

3.0 STATE OF THE PRACTICE

In addition to published access management research, many state agencies develop and publish guidelines or policies for addressing regional access management. In some instances, they base their documents on the published research as summarized in Chapter 2 of this report; however, some states may supplement this information with feedback from local evaluations. Table 3.1 provides a summary of access management web addresses for the various state agencies. This chapter further summarizes criteria or guidelines published for some of these United States transportation agencies. For consistency, the format of this chapter includes categories similar to those shown in Chapter 2.

3.1 OVERVIEW OF GENERAL ACCESS MANAGEMENT STRATEGIES

Access management standards from several states include summary evaluation metrics for the general safety effectiveness of access management. The *Access and Roadside Management Standards* from the South Carolina DOT (*2008*), for example, includes a summary table (see Table 3.2) based on information from the TRB *Access Management Manual* (*2003*).

As the table indicates, the access management treatments introduce a variety of operational and safety enhancements that result in reductions in crashes, improvements to roadway capacity, and decreases in delays. For example, adding a continuous TWLTL may result in a 35-percent reduction in total crashes, 30-percent decrease in delay, and a 30-percent increase in capacity. Among all suggested treatments, a non-traversable median can be expected to introduce the greatest safety benefits with more than a 55-percent reduction in total crashes, and a range of 15-percent up to 57-percent reduction in crashes for multilane roads when a TWLTL is replaced with a non-traversable median.

The Wyoming DOT (*2005*) *Access Manual* indicates that effective access management could reduce crashes by as much as 50-percent. The Wyoming manual cited two tables from a Federal Highway Administration report on access control (*Cirillo 1992*). Included in the Wyoming manual are two tables that demonstrate expected crash rates based on access control (see Table 3.3) as well as annual crashes per mile based on access density and traffic volume (see Table 3.4). Often state access management guidelines and policies identify potential operational benefits as one goal of an effective access management strategy. For example, the Wyoming DOT (2005) Access Manual indicates that appropriate access management may increase capacity from 20-percent up to 45-percent. The Wyoming manual also indicates that access management can potentially reduce travel time and delay by 40-percent to 60-percent and decrease fuel consumption by as much as 35-percent.

Table 3.1: Summary of State Access Management Sites

State	Web Address
Alabama	http://isd.alabama.gov/POLICY/Standard_620-01S1_Access_Management.pd f
Alaska	http://www.dot.state.ak.us/permits/RowdysUsersGuide/drivewayreg.html#tech
Arizona	http://www.azaccessmanagement.com/
Arkansas	---
California	---
Colorado	http://www.dot.state.co.us/AccessPermits/index.htm
Connecticut	---
Delaware	http://www.deldot.gov/information/pubs_forms/manuals/entrance_manual/index.shtm l
Florida	http://www.dot.state.fl.us/planning/systems/sm/accman/
Georgia	http://www.dot.state.ga.us/DOINGBUSINESS/PERMITS/Pages/AccessManagement.aspx
Hawaii	---
Idaho	http://itd.idaho.gov/manuals/Online_Manuals/Current_Manuals/POLICIES/A1201.doc
Illinois	http://www.dot.state.il.us/desenv/BDE%20Manual/BDE/pdf/chap35.pdf#39
Indiana	http://www.in.gov/indot/3273.htm
Iowa	http://www.iowadot.gov/traffic/sections/itsauwz/access.htm
Kansas	http://www.ksdot.org/BurTrafficEng/cmpworking/cmpindex.asp
Kentucky	http://www.planning.kytc.ky.gov/modal_programs/am.asp
Louisiana	http://www.dotd.louisiana.gov/highways/maintenance/maintmgt/msm_row_permits.asp
Maine	http://www.state.me.us/mdot/planning-process-programs/access-mngmnt.php
Maryland	http://www.sha.maryland.gov/Index.aspx?PageId=320
Massachusetts	---
Michigan	http://www.michigan.gov/mdot/0,1607,7-151-9621_11041_29705---,00.html
Minnesota	http://www.dot.state.mn.us/accessmanagement/accessmanagementmanual.html
Mississippi	---
Missouri	http://www.modot.mo.gov/safety/AccessManagement.htm
Montana	http://www.mdt.mt.gov/publications/docs/brochures/tranplan21/accessmgmt.pdf
Nebraska	http://www.nebraskatransportation.org/roway/pdfs/accesscontrol.pdf
Nevada	http://www.nevadadot.com/business/forms/pdfs/TrafEng_AccesMgtSysStandards.pdf
New Hampshire	http://www.nh.gov/dot/org/operations/highwaymaintenance/documents.htm
New Jersey	http://www.state.nj.us/transportation/business/accessmgt/
New Mexico	http://www.nmshtd.state.nm.us/main.asp?secid=11703
New York	https://www.nysdot.gov/portal/page/portal/transportation-partners/nys-transportation federation/permits/residential-driveway-permits
North Carolina	http://www.accessmanagement.info/AM06pdf/AM0622a_Cove.pdf http://www.ncdot.org/doh/PRECONSTRUCT/traffic/safety/Resources/
North Dakota	http://www.dot.nd.gov/manuals/design/designmanual/chapter3/DM-3-16_tag.pdf
Ohio	http://www.dot.state.oh.us/Divisions/ProdMgt/Roadway/AccessManagement/Pages/default.aspx
Oklahoma	---
Oregon	http://www.oregon.gov/ODOT/HWY/ACCESSMGT/
Pennsylvania	ftp://ftp.dot.state.pa.us/public/PubsForms/Publications/PUB%20574.pdf ftp://ftp.dot.state.pa.us/public/Bureaus/Cpdm/WEB/LegislativeandPolicy.pdf ftp://ftp.dot.state.pa.us/public/Bureaus/Cpdm/WEB/BestPracticesinAccessManagement.pdf ftp://ftp.dot.state.pa.us/public/Bureaus/Cpdm/WEB/Stateofthe%20Practicefor%20AccessManagement.pdf
Rhode Island	---
South Carolina	http://www.dot.state.sc.us/doing/encroachment_permit.shtml
South Dakota	http://www.sddot.com/pe/projdev/planning_cp.asp
Tennessee	---
Texas	ftp://ftp.dot.state.tx.us/pub/txdot-info/gsd/manuals/acm.pdf
Utah	http://www.udot.utah.gov/main/f?p=100:pg:2178994586570446:::V,T:,314
Vermont	http://www.azaccessmanagement.com/
Virginia	http://virginiadot.org/projects/accessmgt/default.asp
Washington	http://www.wsdot.wa.gov/Regions/NorthCentral/planning/AccessMgmt.htm http://www.wsdot.wa.gov/Northwest/DevelopmentServices/AccessServices.htm http://www.wsdot.wa.gov/mapsdata/tdo/mobility.htm
West Virginia	http://www.wvdot.com/engineering/Manuals/Traffic/Driveway.pdf
Wisconsin	http://www.dot.wisconsin.gov/business/rules/property-permits.htm#driveway
Wyoming	---

Table 3.2: Summary of Effects of Access Management

Treatment	Effort
Add continuous TWLTL	35% reduction in total crashes
	30% decrease in delay
	30% increase in capacity
Add non-traversable median	≥ 55% reduction in total crashes
	≥ 30% decrease in delay
	≥ 30% increase in capacity
Replace TWLTL with a non-traversable median	15% - 57% reduction in crashes on four-lane
	25% - 50% reduction in crashes on six-lane
Add a left turn improvement	25% - 50% reduction in crashes on four-lane
	up to 75% reduction in total crashes at unsignalized access
	25% increase in capacity
Painted left turn improvement	32% reduction in total crashes
Separator or raised divider for left turn	67% reduction in total crashes
Add right-turn bay	20% reduction in total crashes
	limit right-turn interference with platooned flow, increased capacity
Increased driveways, illumination	42% reduction in crashes
Prohibition of on-street parking	30% increase in traffic flow
	20% to 40% reduction in crashes
Long signal spacing with limited access	42% reduction in total vehicle-hours of travel
	59% reduction in delay
Convert Stop controlled intersection to roundabout	47% reduction of all crashes
	72% reduction of injury crashes

Source: Access Management Manual (TRB 2003)

Table 3.3: Effects of Access Control on Crashes in Urban and Rural Areas

Crash Rates per Million Vehicle Miles				
	Urban		Rural	
Access Control	**Total**	**Fatal**	**Total**	**Fatal**
Full	1.86	0.02	1.51	0.03
Partial	4.96	0.05	2.11	0.06
None	5.26	0.04	3.32	0.09

Source: (Cirillo 1992)

Table 3.4: Annual Access-Related Crashes per mile by Access Density and ADT

Level of Development	Driveways per mile	Highway ADT (Vehicles Per Day)		
		Low < 5,000	**Medium 5,000-15,000**	**High > 15,000**
Low	< 30	12.6	25.1	37.9
Medium	30-60	20.2	39.7	59.8
High	> 60	27.7	54.4	81.7

Source: (Cirillo 1992)

The Vermont DOT *Access Management Program Guidelines* (*2005*) also includes a statement that successful access management will reduce crashes and the potential for future crashes.

The Washington DOT *Highway Access Management Guidebook* (*2002*) indicates that:

"Numerous studies have shown that controlling and limiting access to highways is a cost-effective way to help maintain the safety, capacity, and functional integrity of a highway."

The Iowa DOT *Access Management Handbook* (*2000*) indicates that safety improvement is one of the greatest benefits of access management. The handbook further indicates that a typical access management project in Iowa can result in a 10-percent up to a 65-percent reduction in annual crashes. Access management projects in Iowa have been found to reduce average crashes per vehicle mile traveled by 40-percent, with a 25-percent reduction in personal injury crashes, and almost a 50-percent reduction in property-damage-only crashes.

The Iowa DOT (*2000*) handbook also indicates that access management helps to preserve highway capacity. The handbook summarizes the results of a before and after study performed for several Iowa corridors and indicates that following the implementation of an access management project, the peak hour level of service improved, in some instances, by as much as one full level of service. Table 3.5 shows the resulting level of service for their before-after studies.

Table 3.5: Improvement in Peak Hour Traffic Levels of Service

Project Location	Before Project	After Project
Ames	C	B
Ankeny	C/D	B
Clive	D	B/C
Des Moines	D	B/C
Fairfield	B	B
Mason City	B	B
Spencer	B	B

Source: (Iowa DOT, 2000)

The Missouri DOT (*2006*) *Access Management Guidelines* indicate that enhanced operations are an important aspect of access management, but the guideline also suggests that a variety of gaps in current capacity analysis procedures should be noted as they apply to access management. These include:

- closely spaced traffic signals,
- TWLTLs,
- roundabouts,
- tight diamond interchanges,
- freeway weaves, and
- other unique scenarios.

The Missouri guidance suggests the use of micro-simulation can help in identifying actual operational impacts of access management improvements.

3.2 MEDIAN TREATMENT ALTERNATIVES

Several state agencies have developed guidelines that address the use of median treatments as access management strategies. The Florida DOT (*2006*) publishes a *Median Handbook* that indicates that restrictive medians offer significant safety benefits. For example, a 1993 evaluation of urban multilane highways in Florida indicated that road segments with restrictive medians experienced a 25-percent lower crash rate than at locations with center turn lanes. The handbook further indicates that restrictive medians help prevent head-on crashes, reduce headlight glare, and minimize turning movement crashes. The median has the added benefit of providing a refuge for pedestrians.

The Indiana DOT (*2006*) *Access Management Guide* cites summary tables from NCHRP Report 420 (*Gluck, Levinson, & Stover 1999*) as a basis for estimating expected crash rates by median type in urban/suburban or rural areas (see Table 2.11and Table 2.12 in the previous chapter). The Indiana guide also uses the example of Memorial Drive in Atlanta, Georgia, to demonstrate one example of how replacing a TWLTL with a raised median reduced the total crash rate by 37-percent and the injury rate by 48-percent as shown in Table 3.6.

Table 3.6: Percentage Change in Crash Rates after Replacing a TWLTL with a Raised Median

Location	Total Crash Rate	Injury Rate
Mid-block	-55	-59
Intersection	-24	-40
Total	-37	-48

Source: Access Management Manual (TRB 2003)

The Texas DOT *Access Management Manual* (*2004*) includes the following statement:

"Roadways with nontraversable medians are safer at higher speeds and at higher traffic volumes than undivided roadways or those with continuous two-way left-turn lanes (TWLTL)."

The Texas manual also includes a table similar to Table 2.11 in the previous chapter. Based on previous studies, the Texas manual concludes that roadways with a non-traversable median have about a 30-percent less crash rate than roadways with a TWLTL. The Missouri DOT *Access Management Guidelines* (*2006)* suggest roads with raised medians are at least 25-percent safer than undivided roads and 15-percent safer than TWLTL locations with high traffic volumes.

The South Dakota DOT *Road Design Manual* (*2009*) access management chapter suggests that a continuous raised median with well-designed median openings can reduce crash rates from 40-percent up to 200-percent. The South Dakota DOT manual also indicates that such median configurations can "preserve or raise the operating speed on heavily traveled roadways."

The ODOT access management website includes a series of discussion papers and Discussion Paper No.4 (*Stover 1996a*) summarizes several studies that preceded 1996 and provides a comparison of crash rates as depicted in Table 3.7.

Table 3.7: Average Statewide Total Crash Rates on Divided Highways versus TWLTL

Study	4 Traffic Lanes			6 Traffic Lanes		
	TWLTL	Divided	Divided as a Ratio of TWLTL	TWLTL	Divided	Divided as a Ratio of TWLTL
Georgia	8.99	7.67	0.85	10.82	8.15	0.75
Florida	3.27	2.46	0.75	4.28	3.20	0.75
Michigan	9.56	4.07	0.42	11.07	5.63	0.51

Source: (Stover 1996a)

3.3 SIGNALIZED INTERSECTION SPACING

Several states include signalized intersection spacing guidelines in their access management manuals or policies. For information about safety or operational effectiveness, the individual states generally cite work summarized in NCHRP Report 420 (*Gluck, Levinson, & Stover 1999*). For example, the Indiana DOT *Access Management Guide* (*2006*) cites the figure for urban and suburban crash rates based on signalized intersection spacing (see Figure 2.4 in the previous chapter).

The Missouri DOT *Access Management Guidelines* (*2006*) provide design guidance for spacing based on roadway classification and indicate that adequate spacing tends to reduce rear-end crashes while improving operations and reducing delay.

The Texas DOT *Access Management Manual* (*2004*) demonstrates the percent increase in travel time based on signals per mile that was originally included in NCHRP Report 420 (*Gluck, Levinson, & Stover 1999*). This table is Table 2.14 in the previous chapter of this report.

3.4 UNSIGNALIZED INTERSECTION AND DRIVEWAY SPACING AND PLACEMENT

Recommendations for the placement and spacing of unsignalized intersections and driveways are one of the most common components of access management guidelines and policies for the various states. For example the Florida DOT *Driveway Information Guide* (*2008*) and the Georgia DOT *Regulations for Driveway and Encroachment Control* (*2003*) provide recommendations about driveway placement and spacing strategies. These documents, however, provide only general information about safety or operational benefits of driveways.

The Indiana DOT *Access Management Guide* (*2006*) emphasizes the separation of access or "conflict" points. They indicate that sufficient spacing should be provided between unsignalized access points so that drivers have enough time to expect and recover from the turning movements. The Indiana guidance also indicated that the number of crashes can be expected to increase with an increase in the frequency of access points. In addition to these general observations regarding safety associated with unsignalized access points, the Indiana guide includes one table (based on Table 2.16 in this report) and two figures (see Figure 2.2 and Figure 2.3) that quantify crashes associated with access point density as well as median type and urban, suburban, or rural setting.

The Minnesota DOT *Report to the 1999 Minnesota Legislature, Highway Access Management Policy Study* (*1999*) refers to a Minnesota study that evaluated the statistical relationship between crashes and access points. In this study, they determined that increasing the density of access points will increase the crash rate; however, they noted that this condition is more severe for urban regions. This document also indicated that similar findings occurred for studies in Colorado, Connecticut, Michigan, Oklahoma, and Oregon.

The Missouri DOT *Access Management Guidelines* (*2006*) provides basic guidelines for at-grade intersection spacing for urban and rural areas. The Missouri guideline then stipulates that the use of spacing greater than their recommended values will enhance safety and operations.

3.5 UXILIARY (LEFT-TURN AND RIGHT-TURN) LANE INSTALLATION

Recommendations for the placement and spacing of auxiliary left-turn and right-turn lanes occur in several state access management plans as strategies to enhance safety and improve operations.

The ODOT (*Stover 1996c*) review summarized research that occurred prior to 1996 and indicated that the inclusion of a left-turn bay or lane can improve safety by providing sufficient lengths to meet storage and deceleration requirements. The Oregon paper includes two tables that depict the expected safety effectiveness of left-turn bays for both signalized and unsignalized access points. Table 3.8 demonstrates the expected effect of left-turn bays on crash rates for unsignalized and signalized locations, while Table 3.9 demonstrates crash rates at these locations based on lighting conditions.

Table 3.8: Effect of Left-Turn Bays on Crash Rates

Crash Types	Crash Rates			
	Unsignalized		Signalized	
	No Left Turn Lane	With Left Turn Lane	No Left Turn Lane	With Left Turn Lane
Left Turns	1.2	0.12	0.65	0.37
All Other	3.15*	0.92*	1.82*	1.17*
Total	4.35*	1.04*	2.47*	1.54*

Indicates a statistically significant difference

Source: (Stover 1996c)

Table 3.9: Crash Rates (per million entering vehicles) Before and After Construction of Left-Turn Bays

Light Conditions	Signalized			Unsignalized		
	Rate Before	Rate After	Change	Rate Before	Rate After	Change
Day	0.94	0.73	-22	1.12	0.50	-55
Night	1.12	1.00	-11	1.24	0.73	-41
TOTAL	1.00	0.82	-18	1.16	0.58	-50

Source: (Stover 1996c)

The Indiana DOT (*2006*) *Access Management Guide* indicates that adding a left-turn bay reduces crash rates by 25-percent to 50-percent for four-lane roadways. The Indiana guide also emphasized the importance of left-turn lanes at locations with the potential for extensive blockage of other vehicle movements. Included in the Indiana document is Table 3.10 which was originally published in NCHRP Report 420 (*Gluck, Levinson, & Stover 1999*).

Table 3.10: Proportion of Through Vehicles Blocked as a Function of Left-Turns per Cycle

Left-Turns Per Cycle	Proportion of Through Vehicles Blocked
1	25%
2	40%
3	60%

Source: NCHRP Report 420 (Gluck, Levinson, & Stover 1999)

The Missouri DOT (*2006*) *Access Management Guidelines* provide considerable guidance as to how to determine the need for left-turn lanes and indicates that the installation of these lanes will reduce the frequency of rear-end crashes when there is significant left-turn activity. The Missouri guidelines also recommend installing right-turn acceleration lane at locations with high traffic volumes.

The South Carolina DOT (*2008*) *Access and Roadside Management Standards* includes a similar statement to that in Indiana's guide: adding a left-turn bay will result in a 25-percent to 50-percent crash reduction for four-lane highways. The South Carolina DOT standards also indicate that the inclusion of a left-turn bay results in up to a 75-percent reduction in total crashes at unsignalized intersection or driveway locations, and a 25-percent increase in capacity. The South Carolina standards also indicate that the addition of a right-turn bay will result in a 20-percent reduction in total crashes and will reduce the influence of right-turn vehicles on traffic conditions when platoons are present. This enhancement would then result in an increase in capacity.

3.6 U-TURNS AS ACCESS MANAGEMENT STRATEGIES

There is very little information included in the individual states' access management guidelines or policies regarding the benefits of using U-turns independently or as an alternative to a direct left turn. The Florida DOT (*2009*) did publish a document titled "Access Management: Answers to your questions" and this document indicated that recent research reveals that crashes that cause injuries are reduced by more than 25-percent through encouraging right turns followed by U-turns when compared to direct left turns. The document also indicated that surveys of motorists have shown that the vast majority of drivers have few problems with executing U-turns to access businesses. In fact, most surveyed drivers indicated that access management improvements make roads safer and so they tend to approve of the changes, despite minor inconveniences associated with U-turns.

3.7 ACCESS MANAGEMENT AT INTERCHANGES

The use of access management in the vicinity of intersections and interchanges is emphasized within many state guidelines and policies, but specific safety metrics are not cited in any of the state documents. The Florida DOT (*2009*) brochure "Access Management: Answers to your questions" places a special emphasis on access management in the vicinity of interchanges and stipulates that if there are intersections and/or driveways in close proximity to interchange ramps, the efficient operations of the interchange can deteriorate.

The ODOT (*Layton 1996*) includes reference to a paper on interchange issues within their guidelines. This paper is further reviewed in Chapter 2 of this report.

3.8 ECONOMIC IMPACTS OF ACCESS MANAGEMENT

Several of the state guidelines or policies highlight economic impacts as incentives for the use of access management. For example, the Iowa DOT (2000) *Access Management Handbook* noted that many business owners thought access management projects would significantly reduce turning opportunities for motorists. But five business vitality case studies conducted in Iowa indicated that businesses located within access management corridors generally experienced better sales than their surrounding communities during their study years from 1992 through 1995.

The Washington State *Highway Access Management Guidebook* (*2002*) indicates that their legislature has determined that access management, by improving facility capacity, promotes "sound economic growth and the growth management goals of the state."

The Missouri DOT (*2003*) *Access Management Guidelines* also referred to an expected decrease in business revenues and property values at locations with poor access management. The document suggested that drivers will tend to avoid the routes with high levels of congestion. For locations where the access is well managed, the majority of businesses can expect to experience increased sales and property values. They did suggest that high volume businesses located near mid-block locations could experience a negative impact as a result of reduced access.

The Texas DOT (*2004*) *Access Management Manual* indicates that well designed access and transportation systems are very important for developers and economics. They cite work by the Urban Land Institute that indicates "poorly designed entrances and exits not only present a traffic hazard but also cause congestion that can create a negative image of the center." The Texas document also points to a National Highway Institute study that determined that as much as a 40-percent to 60-percent increase in travel time and delay could result from inadequate access management. They further indicate that 10-percent reductions in average travel speeds can result in a 20-percent loss of business market area. The Texas manual cites several of the studies summarized in Chapter 2 of this report and then concludes that access management has little or no adverse impact on business activity.

The Wyoming DOT *Access Manual* (*2005*) further suggests that access management will protect investments for abutting properties and maximize "the economic value of property by providing better coordination between transportation and adjoining land uses."

The Indiana DOT (*2006*) *Access Management Guide* states that "access management does not only improve the transportation function of the roadway, but it also helps preserve long-term property values and the viability of abutting development."

The Florida DOT (*2009*) document "Access Management: Answers to your questions" indicates that some businesses (doctors, specialty retail stores, service-oriented businesses) are not affected by access management, and some pass-by businesses (convenience stores, gas stations, fast food restaurants) could be affected, but the impacts could be neutral or positive for well designed access management.

4.0 WORK PLAN AND OVERVIEW OF MANUAL DEVELOPMENT

Evaluation and documentation of published research and common practices by other states was a critical first step for the development of an *Oregon Access Management Best Practices Manual*. Armed with this information, the research team developed the manual; however, there are several key factors considered during the creation of the manual.

The research team, along with feedback from the ODOT Technical Advisory Committee (TAC), identified key content for the manual. This data collection and analysis plan includes the research teams' recommendations for the next steps toward completion of this document.

The project proposal, developed following initial feedback from TAC members, recommended that the document contain three key items. The following list briefly identifies these items:

- Develop measurable criteria to evaluate access management techniques and improvements;
- Determine data collection practices necessary to properly measure outcomes and recommend key methods for collecting this data; and
- Develop a manual that concisely integrates the performance measures and data collection strategies and needs for a variety of access management applications.

These three items have been incorporated in the creation of the *Oregon Access Management Best Practices Manual*. During development of this manual, ODOT initiated a research project to assess the safety implications of driveways at Oregon arterial corridors. The manual development, per ODOT recommendation, was paused so that this new content could be included (see Section xx of the draft manual for these recently developed procedures).

Strategies identified to fulfill the three key content items listed above are summarized in the following sections.

4.1 DEVELOP MEASURABLE CRITERIA FOR OREGON "BEST OUTCOMES"

Chapter 2 and Chapter 3 of this report include compiled information available at the time of the initial project phases as published in the literature and other access management state agency documents. In some cases, there is considerable variation in the findings of previous research. For the draft manual, the research team scrutinized conflicting or dramatically varying "best outcomes" to determine accuracy and applicability for the State of Oregon. Rather than include a wide range of values as shown in Chapter 2 of this report, the research team narrowed this information and developed measurable criteria for the evaluation of access management techniques and improvements in Oregon. In addition to content in the literature review of this report, the project team also included content from the recently published *Highway Safety Manual*. The "best outcomes" include quantifiable information that can be used by Oregon transportation agencies to evaluate alternatives and select the access management techniques that best achieve system management goals. This type of information in an Oregon reference manual will help these agencies make more informed system management decisions.

For demonstration purposes, one example of conflicting information is the use of left-turn lanes at urban signalized intersections. Many research efforts simply summarized the effects of left-turn lanes for all locations (without consideration to traffic control, intersection type, or region), while other jurisdictions provided significant detail regarding geometry, phasing, and time of construction (see Table 2.19 for this summary). Another difference in past research is the use of before-and-after studies as compared to cross-sectional studies (where one site has a feature and one does not). Finally, another disparity in the published literature is the use of crash frequency versus crash rate. All of these variations create a wide range of expectations for crash reduction due to left-turn lanes (from as little as a 10-percent reduction to as much as a 56-percent reduction in crashes). The research team scrutinized the collective body of literature and identified appropriate metrics to minimize these disparities so that the user of the manual will be able to consistently assess the access management treatment for the prevailing traffic, geometric, and regional conditions.

In some instances, the published literature is not mature enough to confidently provide quantifiable benefits. This limitation, for example, is apparent for right-turn lanes, roundabouts, and interchanges. Since there is not always sufficient information to provide quantifiable detail for all access management scenarios, the project team has used using a "best outcomes" summary similar to the hierarchical treatment structure used in the recent TRB Series 500 Synthesis where treatments are proven, show promise, or are experimental. For proven treatments, the "best outcomes" identification will define specific quantifiable performance measures for assessment of these treatments. For "show promise" and "experimental", the document will provide anecdotal guidance as available.

4.2 DETERMINE KEY DATA COLLECTION PRACTICES AND METHODS

A key departure of this research effort from the already available access management handbooks is identifying ways to measure and evaluate access management performance within the State of Oregon. Though these methods can be applied to other states or governing jurisdictions, the focus will be on data collection practices by ODOT and how to use existing data collection strategies or enhance data collection methods in order to acquire adequate information to use in quantifying the effects of the access management improvements on safety as well as operations.

As an initial step to determining candidate data for access management evaluations, the project team initiated a series of case studies to help identify confounding influences, readily available data, and difficult-to-acquire (impractical) data options. Since many access management improvements occur on state highways that may be managed by regional jurisdictions such as cities or counties, the project team targeted a variety of arterial and collector corridors for this initial case study assessment. Though these case studies focused primarily on data collection options for roadway segments, much of the information can be extended to intersection-specific assessments and data needs. The actual data from the case studies was not ultimately included in the manual, but rather served as a basis for helping to formulate feasible data requirements.

4.2.1 Overview of General Data Requirements for Case Studies

Within each general access management category in the manual, the research team has included a list of performance measures and required data elements. To test the practicality of acquiring this type of data, the project team acquired site and crash data for the years spanning 2001 to 2005. The project team attempted to identify the traffic volume (ADT), the speed limit, the functional class, the road geometry (number of lanes, median treatments), driveway and other intersection density, and the length for homogeneous roadway corridors. Table 4.1depicts case study summary crash data for twenty example four-lane corridors, while Table 4.2 shows the companion site characteristics for the same four-lane segments. In an effort to provide sites that could be directly compared, Table 4.2 includes an adjusted value for total crashes per mile. Since access management can also be a critical issue on two-lane corridors, the case study analysis was also extended to data requirements for twenty, two-lane segments (see Table 4.3 and Table 4.4 for the crash and site information). In addition to data acquired from the ODOT crash database, the research team acquired additional information from a variety of data sources as shown in Table 4.5

Table 4.1: Data for Crashes (2001 to 2005) and Access Points [Four-lane corridor]

Site	Length (mile)	Direction of Travel	Number of Access Points	Number of Access-Related Crashes									Total Number of Access-Related Crashes
				Other rear end	Left-turn rear end	Left-turn angle	Head-on	Parked*	Side-swipe	Fixed Objects	Pedestrian	Bicycle	
SW Farmington Rd, Beaverton	0.75	EB	3	34	2	0	0	0	0	3	1	0	40
		WB	8	16	1	4	0	0	0	0	0	0	21
Cedar Hills Blvd, Beaverton	0.47	NB	5	8	1	7	0	0	0	0	0	0	16
		SB	6	13	0	3	0	0	0	1	0	0	17
NW Greenwood Ave, Bend	0.51	EB	4	10	0	1	0	4	0	0	0	0	15
		WB	4	14	1	2	0	2	0	0	0	0	19
NE Revere Ave, Bend	0.17	EB	3	1	0	7	0	0	1	0	0	0	9
		WB	3	1	0	1	0	0	0	0	0	0	2
S 1st Ave, Hillsboro	0.44	NB	5	3	0	2	0	0	1	0	1	0	7
		SB	3	8	1	1	0	0	0	0	0	0	10
SE 10th Ave, Hillsboro	0.18	NB	3	6	0	0	0	0	0	1	0	0	7
		SB	3	5	0	3	0	0	0	0	0	0	8
Willamette St, Eugene	0.62	NB	12	19	6	10	0	0	0	0	0	1	36
		SB	14	15	2	30	0	0	0	1	0	0	48
Garfield St, Eugene	0.46	NB	3	26	0	1	0	0	0	0	2	0	29
		SB	8	19	0	0	0	0	0	1	0	0	20
SE Foster Rd, Portland	0.52	SEB	3	7	0	2	0	0	0	0	0	0	9
		NWB	5	6	1	2	0	1	0	0	0	0	10
NE Halsey St, Portland	0.29	EB	3	4	0	1	0	0	0	0	0	1	6
		WB	3	5	1	1	0	1	0	0	0	0	8
SE Holgate Blvd, Portland	0.29	EB	2	2	0	1	0	0	0	0	0	0	3
		WB	2	1	0	0	0	0	0	1	0	0	2
SE Hawthorne Blvd, Portland	0.54	EB	2	6	0	0	0	6	0	0	1	1	14

Site	Length (mile)	Direction of Travel	Number of Access Points	Number of Access-Related Crashes									Total Number of Access-Related Crashes
				Other rear end	Left-turn rear end	Left-turn angle	Head-on	Parked*	Side-swipe	Fixed Objects	Pedestrian	Bicycle	
		WB	3	3	0	0	0	4	0	0	0	1	8
4th St, Medford	0.33	NEB	1	7	0	0	0	0	0	0	0	0	7
		SWB	2	3	1	2	0	0	0	0	1	0	7
Biddle Rd, Medford	0.87	NB	12	22	0	6	0	1	0	2	0	1	32
		SB	0	7	2	0	0	0	0	3	0	0	12
E Burnside St, Portland	0.79	EB	5	12	1	1	1	0	0	0	0	0	15
		WB	6	7	1	1	0	0	1	1	1	1	13
W Burnside St, Portland	0.94	EB	8	21	0	6	0	0	0	3	2	1	33
		WB	10	34	3	2	0	0	0	1	3	1	44
SE 39th Ave, Portland	0.30	NB	3	6	0	3	0	1	0	0	0	0	10
		SB	2	6	1	1	0	0	0	1	0	0	9
SE Division St, Portland	0.44	EB	1	3	0	1	0	0	0	1	0	0	5
		WB	4	4	0	2	0	0	0	1	0	0	7
Kruse Way, Lake Oswego	0.74	EB	0	15	0	0	0	0	0	0	0	0	15
		WB	0	10	0	0	0	0	0	0	0	0	10
Boones Ferry Rd, Lake Oswego	0.84	NEB	18	13	5	11	0	0	0	1	0	0	30
		SWB	16	28	0	11	0	0	0	1	0	0	40

*Parked = impacted a parked vehicle

Table 4.2: Site Information for Urban Commercial Four-lane Corridors

Site	Functional Class	Length (mile)	Total Crashes per mile	Access Density (#/mile)	ADT (veh/day)	Speed limit (mph)	Median Present*	TWLTL Present*
SW Farmington Rd, Beaverton	Urban Principal Arterial	0.75	81.3	14.7	23,400	35	N	P
Cedar Hills Blvd, Beaverton	Urban Minor Arterial	0.47	70.2	23.4	13,607	35	N	P
NW Greenwood Ave, Bend	Urban Minor Arterial	0.51	66.7	15.7	17,258	25	N	N
NE Revere Ave, Bend	Urban Minor Arterial	0.17	64.7	35.3	12,523	30	N	N
S 1st Ave, Hillsboro	Urban Minor Arterial	0.44	38.6	18.2	13,549	25	N	N
SE 10th Ave, Hillsboro	Urban Principal	0.18	83.3	33.3	24,477	30	N	E
Willamette St, Eugene	Urban Minor Arterial	0.62	135.5	41.9	17,900	25	N	N
Garfield St, Eugene	Urban Principal	0.46	106.5	23.9	18,900	30	N	N
SE Foster Rd, Portland	Urban Minor Arterial	0.52	36.5	15.4	22,111	35	N	P
NE Halsey St, Portland	Urban Minor Arterial	0.29	48.3	20.7	19,125	35	N	N
SE Holgate Blvd, Portland	Urban Collector	0.29	17.2	13.8	14,810	30	N	N
SE Hawthorne Blvd, Portland	Urban Minor Arterial	0.54	40.7	9.3	23,132	25	N	N
4th St, Medford	Urban Collector	0.33	42.4	9.1	7,667	25	N	N
Biddle Rd, Medford	Urban Minor Arterial	0.87	50.6	13.8	18,650	35	P	N
E Burnside St, Portland	Urban Principal	0.79	35.4	13.9	25,533	25	N	N
W Burnside St, Portland	Urban Minor Arterial	0.94	81.9	19.1	30,496	25	N	N
SE 39th Ave, Portland	Urban Minor Arterial	0.30	63.3	16.7	22,833	35	N	N
SE Division St, Portland	Urban Collector	0.44	27.3	11.4	22,546	35	N	P
Kruse Way, Lake Oswego	Urban Principal	0.74	33.8	0.0	31,208	40	E	N
Boones Ferry Rd, Lake Oswego	Urban Principal	0.84	83.3	40.5	21,723	30	P	N

* N = none, P = partial, E = entire

Table 4.3: Data for Crashes (2001 to 2005) and Access Points [Two-lane corridor]

Site	Length (mile)	Direction of Travel	Number of Access Points	Number of Access-Related Crashes									Total Number of Access-Related Crashes
				Other rear end	Left-turn rear end	Left-turn angle	Head-on	Parked*	Side-swipe	Fixed Objects	Pedestrian	Bicycle	
SE 13th Ave, Portland	0.44	NB	3	2	0	2	0	4	0	0	0	0	8
		SB	1	2	1	1	0	1	0	1	0	0	6
Milwaukie Ave, Portland	0.83	NB	11	6	0	2	0	5	0	2	0	0	15
		SB	8	6	0	3	1	3	0	0	0	0	13
SW Broadway, Beaverton	0.70	EB	8	1	1	0	0	2	0	0	0	0	4
		WB	13	0	0	0	0	1	0	0	0	0	1
SW 110th, Beaverton	0.36	NB	1	0	0	1	0	0	0	0	0	0	1
		SB	4	0	0	1	0	1	0	0	0	0	2
SW Millikan Way, Beaverton	0.60	SEB	0	1	0	0	0	0	0	0	0	0	1
		NWB	6	3	0	1	0	0	0	0	0	0	4
SW 1st St, Beaverton	0.34	EB	5	1	0	0	0	1	0	0	0	0	2
		WB	3	2	0	0	0	0	0	0	0	0	2
Century St, Bend	0.61	NB	6	0	0	0	0	0	0	0	0	0	0
		SB	6	1	0	0	0	0	0	0	0	0	1
Bond St, Bend	0.54	NEB	0	0	0	0	1	0	0	1	0	0	2
		SWB	0	0	0	0	0	0	0	2	0	0	2
Olive St, Eugene	0.46	NB	5	6	0	0	0	0	0	0	0	0	6
		SB	4	4	0	1	0	1	0	0	0	0	6
Willamette St, Eugene	0.84	NB	8	3	0	3	0	2	0	1	2	1	12
		SB	10	23	2	3	0	3	0	1	0	2	34
W 5th St, Eugene	0.61	EB	6	3	0	0	0	2	0	0	0	0	5
		WB	4	3	0	1	0	0	0	0	0	1	5
E Broadway, Eugene	0.38	EB	3	0	0	0	0	0	0	1	0	0	1

Site	Length (mile)	Direction of Travel	Number of Access Points	Number of Access-Related Crashes									Total Number of Access-Related Crashes
				Other rear end	Left-turn rear end	Left-turn angle	Head-on	Parked*	Side-swipe	Fixed Objects	Pedestrian	Bicycle	
		WB	2	2	0	0	0	2	0	1	1	0	6
NW 23rd Ave, Portland	0.74	NB	6	11	0	1	0	12	0	1	2	0	27
		SB	5	10	0	1	0	6	0	0	0	0	17
NW Hoyt St, Portland	0.29	EB	1	0	0	0	0	2	0	0	0	0	2
		WB	2	0	0	0	0	0	0	0	0	0	0
NW 21st Ave, Portland	0.66	NB	6	4	0	1	0	5	0	0	1	0	11
		SB	7	4	0	1	1	2	0	0	0	0	8
NW Couch St, Portland	0.62	EB	2	1	0	0	0	0	0	0	0	0	1
		WB	5	1	0	0	0	6	0	0	1	0	8
Main St, Oregon City	0.63	NEB	11	0	0	0	0	0	0	0	0	0	0
		SWB	9	2	0	1	0	1	0	0	0	0	4
Washington St, Oregon City	0.37	NEB	1	0	0	0	1	1	0	0	0	0	2
		SWB	4	3	0	1	0	0	0	0	0	0	4
Jackson St, Medford	0.28	EB	2	0	0	0	0	0	0	0	0	0	0
		WB	0	1	1	0	0	0	0	0	0	0	2
Main St, Medford	0.48	EB	4	2	1	2	0	0	0	0	1	0	6
		WB	4	4	0	3	0	0	0	0	0	0	7

*Parked = impacted a parked vehicle

Table 4.4: Site Information for Urban Commercial Two-lane Corridors

Site	Functional Class	Length (mile)	Total Crashes per mile	Access Density (#/mile)	ADT **(veh/day)**	Speed limit (mph)	Median **Present***	TWLTL **Present***
SE 13th Ave, Portland	Urban Collector	0.44	31.8	9.1	9,425	30	N	N
Milwaukie Ave, Portland	Urban Collector	0.83	33.7	22.9	9,551	30	N	N
SW Broadway St, Beaverton	Urban Collector	0.70	7.1	30.0	3,097	20	P	N
SW 110th St, Beaverton	Urban Collector	0.36	8.3	13.9	2,886	25	N	N
SW Millikan Way, Beaverton	Urban Collector	0.60	8.3	10.0	8,000	35	N	N
SW 1st St, Beaverton	Urban Local Street	0.34	11.8	23.5	1,210	20	P	N
Century St, Bend	Rural Minor Arterial	0.61	1.6	19.7	6,793	35	P	P
Bond St, Bend	Rural Minor Arterial	0.54	7.4	0.0	8,534	25	N	P
Olive St, Eugene	Urban Local Street	0.46	26.1	19.6	5,980	20	P	N
Willamette St, Eugene	Urban Minor Arterial	0.84	54.8	21.4	6,483	25	P	P
W 5th St, Eugene	Urban Local Street	0.61	16.4	16.4	6,757	25	N	N
E Broadway, Eugene	Urban Local Street	0.38	18.4	13.2	3,600	15	P	N
NW 23rd Ave, Portland	Urban Collector	0.74	59.5	14.9	11,540	25	N	N
NW Hoyt St, Portland	Urban Local Street	0.29	6.9	10.3	8,422	25	N	N
NW 21st Ave, Portland	Urban Collector	0.66	28.8	19.7	8,923	20	N	N
NW Couch St, Portland	Urban Local Street	0.62	14.5	11.3	1,991	20	N	N
Main St, Oregon City	Urban Collector	0.63	6.3	31.7	6,155	25	N	N
Washington St, Oregon City	Urban Minor Arterial	0.37	16.2	13.5	8,330	25	N	N
Jackson St, Medford	Urban Collector	0.28	7.1	7.1	7,450	30	N	N
Main St, Medford	Urban Minor Arterial	0.48	27.1	16.7	11,500	30	N	N

* N = none, P = partial

Table 4.5: Sources for Required Case Study Data

Data Variable (unit)	Source
Access density (#/mile)	Google Earth
Average daily traffic (veh/day)	City or ODOT website
Speed limit (mph)	ODOT
Presence of raised medians	Google Earth
Presence of TWLTLs	Google Earth

4.2.2 Sample Case Studies

As an example of the type of information that can be acquired for a specific site, the following three sample case studies represent site summaries from the targeted case study. The project team has developed similar case study summaries for all forty sample case studies.

4.2.2.1 East Burnside Street, Portland, Oregon

East Burnside Street is an urban principal arterial located in Portland, Oregon. It is oriented in the east-west direction. The study area consists of two through travel lanes in each direction between East Martin Luther King Blvd. and East 20th Avenue. The total length is 0.79 miles. The road is approximately 50 feet wide, and on-street parking is permitted in some sections. The posted speed limit on this segment of the road is 25 mph. The local business includes several restaurants and grocery stores.

There are sidewalks along this road, but no bicycle lanes. There are no medians implemented in the study area. The plan view layout of the study area is presented in Figure 4.1. The street view is provided by Google Earth as shown in Figure 4.2.

Source: Google Earth

Figure 4.1: Plan View Aerial Photo for East Burnside Street, Portland, Oregon

Source: Google Earth

Figure 4.2: Street View of East Burnside Street, Portland, Oregon

The daily traffic volume (2001-2005) is approximately 25,533 vehicles for both directions of travel. The data was acquired from the City of Portland, Oregon website. Table 4.6 outlines the driveway spacing and access control for each driveway in the study area.

Table 4.6: Driveway Locations for East Burnside Street, Portland, Oregon

Intersection Location	East Bound Driveway Spacing (feet)	West Bound Driveway Spacing (feet)
Martin Luther King Blvd	None	None
Grand Ave	74	205
E 6th Ave	None	170
E 7th Ave	None	93
E 8th Ave	None	None
E 9th Ave	None	166
E 10th Ave	None	None
E 11th Ave	103	None
E 12th Ave	None	None
Sandy Blvd	79	None
E 13th Ave	None	103
E 14th Ave	None	None
E 17th Ave	None	None
E 18th Ave	103	None
E 19th Ave	174	74

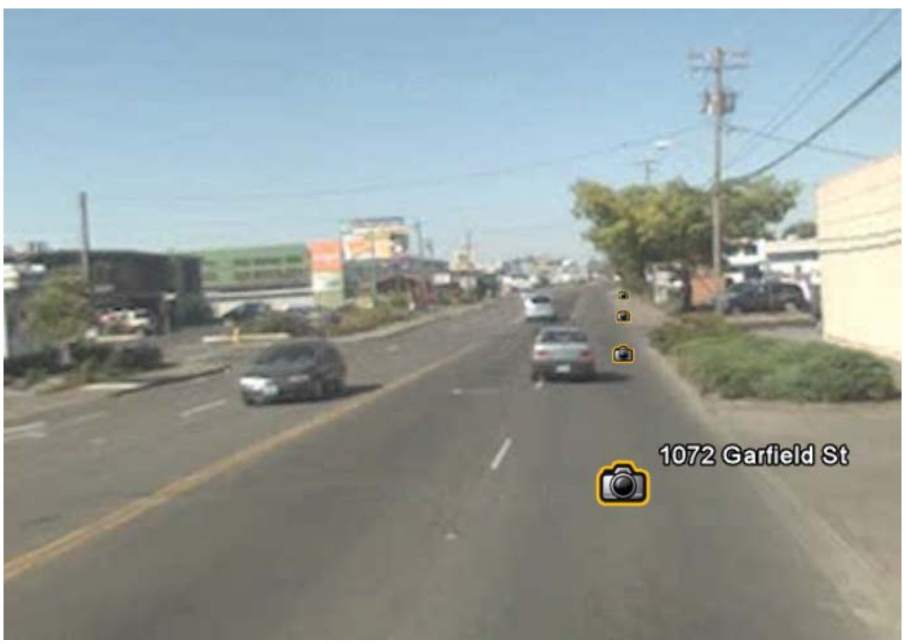
4.2.2.2 Garfield Street, Eugene, Oregon

Garfield Street is an urban principal arterial located in Eugene, Oregon. It is oriented in the north-south direction. The study area consists of two travel lanes in each direction between West 12th Avenue and West 6th Avenue. The total length is 0.46 miles. The road width varies from 40 ft to 50 ft, and on-street parking is not permitted on either side of the road. The posted speed limit on this segment of the road is 30 mph. The local business includes several restaurants and grocery stores.

There are sidewalks along this road, but no bicycle lanes. There are no medians in the study area. The plan view layout of the study area is presented in Figure 4.3. The street view is provided by Google Earth as shown in Figure 4.4.

Source: Google Earth

Figure 4.3: Plan View Aerial for Garfield Street, Eugene, Oregon



Source: Google Earth

Figure 4.4: Street View for Garfield, Eugene, Oregon

The daily traffic volume (2001-2005) is approximately 18,900 vehicles for both directions of travel. The data was acquired from information available at the City of Eugene website. Table 4.7 outlines the driveway spacing and access control for each driveway in the study area.

Table 4.7: Driveway Locations for Garfield Street, Eugene, Oregon

Intersection Location	North Bound Driveway Spacing (feet)	South Bound Driveway Spacing (feet)
W 12th Ave	None	101
W 12th Ave	None	124
W 11th Ave	None	191
W 10th Ave	None	158
W 10th Ave	None	69
W 9th Pl	141	89
W Broadway St	None	None
W 8th Ave	None	None
W 7th Ave	220	83
W 7th Ave	125	62

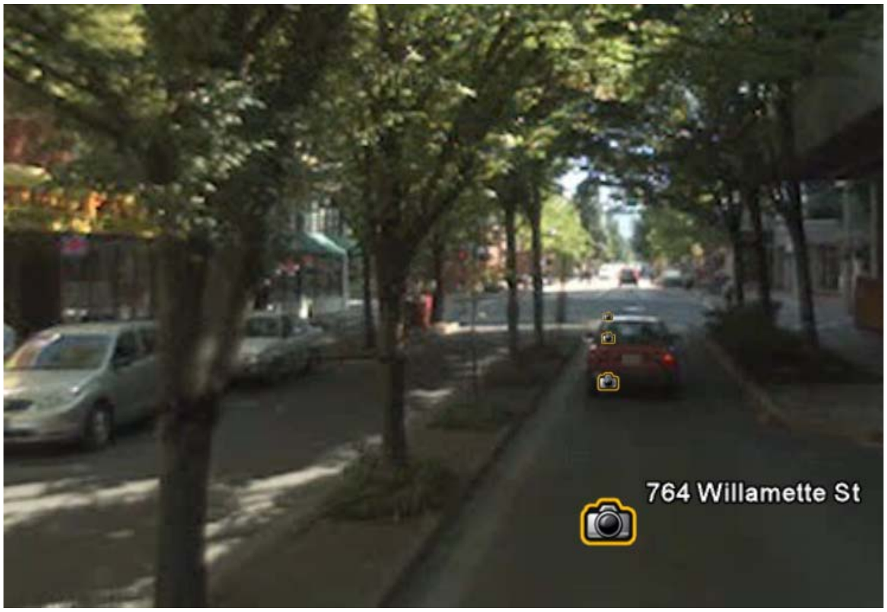
4.2.2.3 Willamette Street, Eugene, Oregon

Willamette Street is an urban minor arterial located in Eugene, Oregon. It is oriented in the north-south direction. The study area consists of one travel lane in each direction between 18th Street and 7th Street. The total length is 0.84 miles. The road width is approximately 40 ft, and on-street parking is permitted in some sections. The posted speed limit on this segment of the road is 25 mph. The local business includes several restaurants, coffee houses, and grocery stores.

There are sidewalks along this road, but no bicycle lanes. Raised intersections and curbs are installed to control traffic in part of the study area. TWLTLs are installed between 13th Street and 11th Street. The plan view layout of the study area is presented in Figure 4.5. The street view is provided by Google Earth as shown in Figure 4.6.

Source: Google Earth

Figure 4.5: Plan View Aerial of Willamette Street, Eugene, Oregon



Source: Google Earth

Figure 4.6: Street View of Willamette Street, Eugene, Oregon

The daily traffic volume (2001-2005) is approximately 6,483 vehicles for both directions of travel combined. The data was acquired from the City of Eugene website. Table 4.8 outlines the driveway spacing and access control for each driveway in the study area.

Table 4.8: Driveway Locations of Willamette Street, Eugene, Oregon

Intersection Location	North Bound Driveway Spacing (feet)	South Bound Driveway Spacing (feet)
18^{th} St	73	70
18^{th} St	28	78
18^{th} St	46	None
18^{th} St	184	None
17^{th} St	228	193
16^{th} St	135	64
15^{th} St	255	67
14^{th} St	96	191
13^{th} St	None	191
12^{th} St	None	154
12^{th} St	None	65
11^{th} St	None	138
10^{th} St	None	None
Broadway St	None	None
8^{th} St	None	None

4.3 OVERVIEW OF THE PROPOSED MANUAL

The product of this research effort is the creation of the *Oregon Access Management Best Practices Manual.* This resulting document can be used by engineers, decision makers, and educators to help the transportation community better understand the appropriate application of access management strategies and how to quantify the benefits of various access management options.

The *Manual* will be an educational tool to help governing jurisdictions communicate and market the principles and benefits of access management. It will help establish consistent statewide understanding, expectations, and application of access management techniques. Quantifying the impacts that access management has on the entire system will lend credibility to the use of these treatments for safety and mobility improvements.

The following is an outline of the basic manual content.

<u>Outline for the *Oregon Access Management Best Practices Manual*</u>

Chapter 1 – Manual Overview and Purpose
Chapter 2 – Access Management Performance Measures
- 2.1 Intersections
  - 2.1.1 Signalized Intersections
  - 2.1.2 Unsignalized Intersection
    - 2.1.2.1 Public Street Intersections
    - 2.1.2.2 Driveway Connections
    - 2.1.2.3 Roundabouts
- 2.2 Interchanges
- 2.3 Auxiliary Lanes
- 2.4 Median Treatments
  - 2.4.1 Raised (Non-Traversable) Medians
  - 2.4.2 Two-Way Left-Turn Lanes
- 2.5 U-turns
- 2.6 Combined Effects

Chapter 3 – Data Needs
- 3.1 Intersection Data Needs
- 3.2 Corridor or Segment Data Needs

Chapter 4 – Documentation and Implementation
Chapter 5 – References
Chapter 6 – Appendix A
- 6.1 Relative Risk Assessment

Chapter 7 -- Example Problem for Driveway Assessment (Urban)
Chapter 8 -- Example Problem for Driveway Assessment (Rural)

5.0 CONCLUSIONS

This final report incorporates the results from the access management best practices research project and summarizes the published literature relevant to this topic. In particular, the literature review (see Chapter 2) identifies expected benefits of deploying various access management strategies. These benefits are generally available as safety or operational benefits; however, some research has been developed on the expected economic benefits of access management scenarios. Chapter 3 expands on the published literature by summarizing general information in the various state agencies' policies and guidelines. Chapter 4 of this report provides information about the overall work activity including sample data collection and an outline that summarizes the companion manual (included as a standalone document).

The primary goal of this report was to summarize the body of knowledge regarding benefits of access management and help to develop a way for Oregon agencies to develop a systematic assessment process for determining the effectiveness of access management strategies.

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APPENDIX A:
ABBREVIATIONS AND ACRONYM DEFINITIONS

Abbreviation / Acronym	Definition
AADT	Average Annual Daily Traffic
ADT	Average Daily Traffic
ARRB	Australian Road Research Board
DLT	Direct Left Turns
DOT	Department of Transportation
FHWA	Federal Highway Administration
ft	Feet
HCM	Highway Capacity Manual
LT	Left Turn
mph	Miles per hour
NCHRP	National Cooperative Highway Research Program
NHI	National Highway Institute
NJDOT	New Jersey Department of Transportation
NYDOT	New York Department of Transportation
ODOT	Oregon Department of Transportation
RT	Right turn
RTUT	Right turn followed by a U-Turn
TAC	Technical Advisory Committee
TRB	Transportation Research Board
TWLTL	Two-way left-turn lane
USDOT	United States Department of Transportation
UT	U-turn
VMT	Vehicle miles travelled
vph	Vehicles per hour
vphpl	Vehicles per hour per lane