Georgia DOT Research Project 19-15

Final Report

SAFETY PERFORMANCE OF RURAL FOUR-LANE UNDIVIDED ROADWAYS AND RURAL FOUR-LANE ROADWAYS WITH A TWO-WAY LEFT-TURN LANE

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7. Author(s) Jun Liu, Ph.D. https://orcid.org/0000-0002-6336-4931 Praveena Penmetsa, Ph.D. https://orcid.org/0000-0001-9003-7568 Xiaobing Li, Ph.D. https://orcid.org/0000-0003-3425-743X Timothy E. Barnett, P.E., PTOE, RSP. https://orcid.org/0000-0002-7073-8751	**8. Performing Organization Report No.** N/A
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16. Abstract

Non-traversable medians consistently yielded improved safety performance compared to other median types such as undivided, 4-feet flush medians, and two-way left-turn lane cross-sections. However, constructing non-traversable medians can be costly. The goal of this study is to 1) examine the safety performance of existing rural four-lane roadways with above-mentioned four median types in Georgia by using Safety Performance Functions (SPFs) and Crash Modification Factors (CMFs), and 2) develop criteria to determine under what conditions these four median types yield maximum safety benefits while considering construction costs. Data were refined and integrated from multiple sources such as from the Georgia Department of Transportation (GDOT), Federal Highway Administration (FHWA) and Google Maps. The Annual Average Daily Traffic (AADT), truck percentage, and access point density were considered as key independent variables in SPFs. The CMFs were estimated to show the effectiveness of a cross-section compared to the base- four-lane undivided roadway. Note, the SPFs and CMFs developed in this study did not consider the speed limit. The key results show that the estimated CMFs vary across different values of variables, indicating that the safety effectiveness of a treatment is likely to vary across different roadway and traffic conditions. Specifically, the segments with non-traversable medians outperformed the other three segment types across all AADTs, truck percentages, and access point densities, except at very low AADT under 5,000 where the 4-feet flush medians appear to have improved safety. The research team estimated average annual crash reductions (compared with undivided roadways), which were converted into monetary values using the average crash costs by severities. The safety benefits and project construction costs were used to estimate benefit-cost ratios (BCRs). Simulations were suggested in situations where safety solely did not help in the decision-making process of identifying cost-effective median type for rural four-lane roadways. It is highly recommended that decision-makers or practitioners use the estimated safety benefits from this study and the construction costs of a specific highway project to estimate BCRs for recommendations of the cross-section type.

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Final Report

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By

Jun Liu, Ph.D., Principle Investigator
Assistant Professor, Department of Civil, Construction, and Environmental Engineering
College of Engineering, The University of Alabama
jliu@eng.ua.edu

Praveena Penmetsa, Ph.D., Co-Principle Investigator
Associate Research Engineer, Alabama Transportation Institute
The University of Alabama
ppenmetsa@ua.edu

Xiaobing Li, Ph.D., Co-Principle Investigator
Associate Research Engineer, Alabama Transportation Institute
The University of Alabama
xli158@ua.edu

Timothy E. Barnett, P.E., PTOE, RSP, Co-Principle Investigator
Operations & Safety Engineer, Alabama Transportation Institute
The University of Alabama
tebarnett1@ua.edu

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EXECUTIVE SUMMARY

Non-traversable medians (NTMs) consistently yielded improved safety performance compared to other median types such as undivided, 4-feet flush medians (4FMs), and two-way left-turn lane (TWLTL) cross-sections. However, constructing NTMs can be costly because of added right-of-way and additional construction costs. The goal of this study is (1) to examine the safety performance of existing rural four-lane (4L) roadways with NTM, TWLTL, 4FM, and UR (undivided roadways) with speed limit 50 mph or higher in Georgia, and (2) to develop criteria to determine under what conditions these four median types yield maximum safety benefits while considering the cost of construction.

Extensive data cleaning and manipulation were adopted to refine the data. Data were pulled from various sources, including the Georgia Department of Transportation (GDOT), Federal Highway Administration (FHWA), and Google Maps. Manual data extractions were performed for uncompiled data such as the number of access points, along with manual verification of median types. Traffic volume data, crash data and roadway data were integrated into datasets for safety performance analysis.

Safety Performance Functions (SPFs) and Crash Modification Factors (CMFs) were used to create the criteria for median recommendation. SPFs were developed for all the four median types. The Annual Average Daily Traffic (AADT), truck percentage, and access point density were considered as independent variables in the SPFs. The SPFs were developed to predict the crash frequencies for different severities, which were used in the criteria. The CMFs were calculated to show the effectiveness of a cross-section compared to the base cross-section, which is a 4L-UR.

The CMFs vary across different values of AADT, segment length, truck percent, and access point density, indicating that the safety effectiveness of a treatment on roadways is also likely to vary across different situations. The key findings based on estimated CMFs are as follows:

- The segments with NTMs outperformed the other three segment types across all AADTs, truck percentages, and access point densities, except at very low AADT around or lower than 5,000 where the 4FMs appear to be associated with an improved condition.
- AADT – Is a principal factor to show the effectiveness of a cross-section compared to the base. In general, the 4FMs appear to have an improved performance than UR segments when the AADT is around or lower than 10,000; when the AADT increases (around or higher than 10,000), the TWLTLs have an improved performance than UR sections and 4FMs; when the AADT reaches 20,000, the NTMs may be considered.
- Truck percentage – Is positively related to the safety effectiveness of 4FM, TWLTLs, and NTMs compared to UR sections. In other words, converting a 4L-UR segment into one of the other three cross-section types can result in an even further improved condition for traffic with a higher truck percentage.
- Access point density – Is negatively related to the safety effectiveness of 4FMs, TWLTLs and NTMs compared to the base segment type. In other words, the safety effectiveness of these three types of medians decreases with the increase in the number of access points along a segment.

Note that, the safety performance on roadways may be associated with the posted speed limits. The estimation of SPFs/CMFs in this study did not consider the impact of speed limits. According to a preliminary study in Appendix A, a higher speed limit is likely associated with a greater rate for fatal and serious injury crashes.

Besides estimating CMFs, to facilitate criteria development and make recommendations on the median type, the research team estimated average annual crash reductions (compared with URs). These crash reductions were converted into monetary values using the average crash costs by severities. The safety benefits (shown below) and the project costs could be used to estimate benefit-cost ratios.

Safety benefits (in $million) for 4FMs, TWLTLs, and NTMs

	Truck Percentage	Vehicle AADT																							
		<=5,000				>5,000 to 10,000				>10,000 to 15,000				>15,000 to 20,000				>20,000 to 25,000				>25,000			
		Access Point Density, AP/mile																							
		<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30
4-ft Flush Median	<=5%	$7	$7	$8	$6	$16	$17	$17	$16	$17	$15	$13	$18	$8	$2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>5% to <=10%	$8	$9	$9	$8	$18	$18	$18	$17	$17	$16	$14	$18	$8	$3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>10% to <=15%	$10	$10	$11	$9	$19	$20	$20	$18	$18	$16	$15	$18	$7	$3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>15% to <=20%	$12	$12	$13	$11	$20	$21	$22	$20	$18	$17	$15	$18	$7	$3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>20%	$14	$15	$16	$13	$22	$23	$24	$21	$18	$17	$16	$18	$7	$3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TWLTL	<=5%	$3	$2	$2	$3	$14	$14	$13	$15	$30	$30	$29	$30	$49	$49	$48	$49	$71	$71	$70	$69	$93	$95	$95	$91
	>5% to <=10%	$5	$5	$5	$5	$19	$19	$19	$18	$35	$35	$35	$34	$51	$53	$53	$50	$69	$71	$72	$67	$87	$90	$92	$84
	>10% to <=15%	$8	$8	$8	$7	$23	$23	$24	$22	$37	$39	$40	$36	$52	$54	$56	$49	$66	$69	$71	$63	$80	$84	$87	$77
	>15% to <=20%	$10	$11	$11	$10	$26	$27	$28	$24	$39	$41	$43	$37	$51	$53	$56	$48	$62	$65	$68	$59	$73	$77	$80	$69
	>20%	$13	$14	$15	$12	$28	$30	$32	$26	$39	$42	$44	$37	$49	$52	$55	$46	$57	$61	$64	$54	$65	$69	$73	$61
Non-traversable	<=5%	N/A	N/A	N/A	N/A	$3	$2	$1	$3	$19	$20	$20	$19	$41	$43	$44	$39	$66	$70	$73	$62	$93	$99	$106	$87
	>5% to <=10%	N/A	N/A	N/A	N/A	$9	$9	$9	$9	$25	$26	$26	$23	$43	$45	$48	$40	$62	$66	$71	$59	$83	$89	$95	$78
	>10% to <=15%	$2	$2	$2	$2	$14	$15	$15	$13	$28	$30	$31	$27	$43	$46	$49	$40	$59	$63	$67	$55	$74	$80	$85	$69
	>15% to <=20%	$6	$6	$6	$5	$18	$19	$20	$17	$31	$33	$35	$29	$43	$46	$49	$40	$54	$58	$62	$51	$66	$71	$76	$61
	>20%	$9	$10	$10	$9	$22	$24	$25	$20	$32	$35	$37	$30	$42	$45	$48	$39	$50	$54	$58	$47	$58	$62	$67	$54

Notes: The base cross-section type is undivided roadways. The safety benefits cover reductions in all crash types. The safety benefits of 20 years are estimated. Cells with "N/A" are estimated with negative safety benefits. The results are applicable to roadways with posted speed limits of 50 mph and higher.

The research team gathered project costs from GDOT and several openly available sources and estimated Benefit-Cost Ratios (BCRs) considering the upper bound of the project costs and developed the following criteria for cross-section recommendation.

Preliminary criteria for recommending cross-section on four-lane rural roadways

Truck Percentage	Vehicle AADT																							
	<=5,000				>5,000 to 10,000				>10,000 to 15,000				>15,000 to 20,000				>20,000 to 25,000				>25,000			
	Access Point Density, AP/mile																							
	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30
<=5%	A	A	A	A	B	B	B	B	B/C	B/C	B/C	B/C	C/D	C/D	C/D	C/D	D	D	D	D	D	D	D	D
>5% to <=10%	A/B	A/B	A/B	A/B	B	B	B	B	B/C	B/C	B/C	B/C	C/D	C/D	C/D	C/D	D	D	D	D	D	D	D	D
>10% to <=15%	A/B	A/B	A/B	A/B	B/C	B/C	B/C	B/C	B/C	B/C	B/C	B/C	C/D	C/D	C/D	C/D	D	D	D	D	D	D	D	D
>15% to <=20%	A/B	A/B	A/B	A/B	B/C	B/C	B/C	B/C	B/C	B/C	B/C/D	B/C/D	C/D	C/D	C/D	C/D	D	D	D	D	D	D	D	D
>20%	B	B	B	B	B/C	B/C	B/C	B/C	B/C	B/C/D	B/C/D	B/C/D	C/D	C/D	C/D	C/D	D	D	D	D	D	D	D	D

Notes: A: Four-Lane Undivided

B: Four-Lane Divided w/4-ft Flush Median

C: Four-Lane Divided w/TWLTL

D: Four-Lane Divided w/Non-Traversable Median or Barrier

When multiple letters (e.g., A/B, or B/C) are given in a cell, simulations were suggested to further examine and compare the performance of alternative cross-section designs. The performance may be examined from safety, mobility, and environmental aspects. It is important to note that, the criteria table provides rough cross-section recommendations merely based on the estimated crash reductions, empirical crash costs, and project costs from the previous projects. The project cost is project-specific, and it can vary substantially from location to location in a state due to various factors, including the prior conditions of a project site, local labor cost, and material cost, etc. The findings are limited to the scope of this project (rural 4L roadways with NTM, TWLTL, 4FM, and UR with speed limit 50 mph or higher in Georgia). It is highly recommended that decision-makers or practitioners use the safety benefits table to compare with the cost of a specific proposed project and make a more realistic recommendation of the cross-section type.

TABLE OF CONTENTS

Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	average daily traffic
AIC	Akaike Information Criterion
APD	access point density
BCR	Benefit-cost ratio
BLS SIO	Bureau of Labor Statistics Southeast Information Office
CMF	Crash Modification Factors
DOT	Department of Transportation
DON	Department of Numbers
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FM	Flush Median
GDOT	Georgia Department of Transportation
GRIP	Governors' Road Improvement Program
GIS	Geographic Information System
HPMS	Highway Performance Monitoring System
HSM	Highway Safety Manual
ITD	Idaho Transportation Department
MPO	metropolitan planning organization
NB	negative binomial
NPV	Net Present Values

NTM	non-traversable medians
SCDOT	South Carolina Department of Transportation
SPF	Safety Performance Function
TWLTL	two-way left-turn lane
TxDOT	Texas Department of Transportation
UR	undivided roadways
TP	truck percentage
4FM	four-feet flush median
4L	four-lane

Chapter 1: INTRODUCTION

Background

The Governors' Road Improvement Program (GRIP) in Georgia was initiated in 1989 to improve the transportation infrastructure across the state. The current extent of the GRIP system consists of 19 corridors with more than 3,300 centerline miles of roadway. When completed, the GRIP system will place 98 percent of Georgia's population within 20 miles of a four-lane highway and connect 95 percent of cities with a population of more than 2,500 to the Interstate System (GDOT, 2018a). Studies indicate that the GRIP fosters economic growth in several ways, including expanding access to markets, reducing shipping costs, increasing per capita income, decreasing unemployment rates, and adding buying power (Bachtel et al., 1998; Humphreys, 2003).

Per the GRIP, the Georgia Department of Transportation (GDOT) is committed to convert existing primary routes and truck access routes into four-lane (4L) roadways. When a 4L road is divided with non-traversable medians (NTMs), it provides more effective and efficient transportation, and safer travel compared to a two-lane highway (Council et al., 1999). However, due to the cost of right-of-way acquisition, construction costs, and/or terrain restrictions in certain areas, 4L Undivided Roadways (UR) or 4L divided roadways with 4-feet wide Flush Medians (4FM) are sometimes proposed and constructed. The environmental impact-related costs should also be considered as part of the project cost; such costs may include the traffic delay costs, and extra fuel consumption and increased emissions due to a project construction (Clavenger and Kociolek, 2006). Studies have found that 4L-UR can experience a degradation of service and/or safety as traffic volumes increase (Knapp and Giese, 2001). The crash rate on 4L-UR can be higher than on two-lane roads because 4L roads carry greater traffic volumes, have a higher frequency of intersections and other access points, and have greater development of adjacent land (AASHTO, 2011). Within 4L roads, divided roads with NTMs have measurably lower collisions compared to URs (Mohamedshah et al., 1994; TxDOT, 2020). 4L-UR should be proposed only under reasonable circumstances that consider the posted speed limits, traffic volume, truck percentage, access points and other factors that could affect traffic safety (Shea et al. 2000).

A 4L roadway with a two-way left-turn lane (TWLTL) may be considered in place of a 4L-UR section as it has an added benefit of providing a separate lane for left-turning traffic that provides the safety benefit of separating left-turning traffic from higher speed and higher volume of through traffic. As the number of access points increases, both safety and operational benefits are recognized with the use of a TWLTL on 4L roads (Ballard and McCoy, 1983; Hovey and Chowdhury, 2005). When average daily traffic volumes exceed 20,000 ~ 24,000 and the demand for mid-block turns is high, a raised or non-traversable median rather than a TWLTL would be recommended (Kentucky DOT, 2019; TxDOT, 2020).

It is essential to understand under what roadway and traffic conditions a given median type yields maximum safety benefits considering its cost effectiveness especially on 4L rural roads. This could help design engineers choose an optimal median type and be proactive in ensuring the safety of drivers.

Project Objectives

The objectives of this project are: (1) to examine the safety performance of existing rural 4L roadways with NTM, TWLTL, 4FM, and UR in Georgia, and (2) to develop criteria to determine under what conditions these four median types yield maximum safety benefits while considering the cost of construction. Specifically, this project:

1. Investigated characteristics of crashes on rural 4L roads with NTM, TWLTL, 4FM, and UR in Georgia;
2. Developed safety performance functions (SPFs) with key factors that significantly influence crash frequencies on 4L roads;
3. Identified key characteristics such as traffic volume, truck percentage, posted speed limit, lane width and access point density which are related to safety sharp deterioration to an undesirable level on rural 4L roads with NTM, TWLTL, 4FM, and UR;
4. Developed a set of guidance criteria to determine when it would be appropriate to consider an NTM, TWLTL, 4FM, and UR on 4L roads in rural areas.

To achieve the objectives of this study, a data-driven approach was adopted following the recommendations listed out in the Highway Safety Manual (HSM).

The rest of the report is organized as follows: literature review, data and methodology, descriptive analysis of the data, safety performance functions, crash modification factors, criteria development, and summary.

Chapter 2: LITERATURE REVIEW

A detailed review of the literature was conducted to examine studies that were relevant to this study's objectives and are presented in this section. The authors split the review results into DOT and scholarly guidelines.

State DOTs

Iowa DOT issues the Design Manual for highways in Iowa (Iowa DOT, 2019). Per Chapter 6, Geometric Design, TWLTLs are recommended only for suburban and urban areas as they could be confused with passing lanes in rural areas. The average daily traffic (ADT) over 10,000 to 12,000 vehicles per day (vpd) would warrant consideration of a TWLTL on a 4L road. When the ADT on a street exceeds about 17,000 vpd, 4L with raised medians or five-lane roadways with TWLTL is more appropriate designs. The limit for TWLTL facilities is approximately 24,000 ADT. TWLTL should generally not be used in when ADT is greater than 24,000 vpd.

Florida DOT sponsored a study to investigate the safety issues related to TWLTLs and the study analyzed more than 1600 road segments with TWLTLs and identified critical traffic volumes by access point density for 4L roads (Pernia et al., 2004). Figure 1 shows the critical AADT (Annual Average Daily Traffic) values for safety improvements at road segments with TWLTLs.

Access Density (points per mile)	Critical AADT (vpd) Percentile Values					
	50%	75%	80%	85%	90%	95%
10	30,073	40,611	42,989	45,640	48,524	53,494
20	28,512	39,050	41,428	44,079	46,963	51,933
30	26,951	37,489	39,867	42,518	45,402	50,372
40	25,390	35,928	38,306	40,957	43,841	48,811
50	23,829	34,367	36,745	39,396	42,280	47,250
60	22,268	32,806	35,184	37,835	40,719	45,689
70	20,707	31,245	33,623	36,274	39,158	44,128
80	19,146	29,684	32,062	34,713	37,597	42,567
90	17,585	28,123	30,501	33,152	36,036	41,006
100	16,024	26,562	28,940	31,591	34,475	39,445
110	14,463	25,001	27,379	30,030	32,914	37,884
120	12,902	23,440	25,818	28,469	31,353	36,323
130	11,341	21,879	24,257	26,908	29,792	34,762
140	9,780	20,318	22,696	25,347	28,231	33,201

Figure 1. Critical AADT values for 4l roads for the higher speed category (Pernia et al., 2004).

Alabama DOT studied approximately 300 miles of roadways in Alabama and proposed 4 different alternatives to improve both operational and safety deficiencies. They relied on previously conducted studies to make alternative determinations (Barnett and Wallace, 2010).

Kentucky DOT's Highway Access Management provided the following guidelines for TWLTL on multi-lane roads in urban/suburban areas: 1) projected ADT of less than 24,000 vpd 2) access point density between 10 and 85 per mile, 3) left turn volume less than 100 vph. Further, they also recommend flush medians to be used when access point density is less than 10 per mile. However, the flush medians are to provide a consistent cross-session rather than for safety or traffic operations (KDOT, 2019). Note, TWLTLs are also considered as flush medians. In this reference, the width of flush medians is not specified.

Texas DOT's Roadway Design Manual suggests the use of TWLTL on 4L suburban roads when the future ADT is around 6,000 vpd and with over 10 entrances per mile (TxDOT, 2020). Another study conducted by Texas Transportation Institute in 1993 states that there are no statistical differences in accident rates of highways with TWLTLs and highways with flush medians when driveway densities are low (e.g., less than 9 driveways per mile) (Balke and Fitzpatrick, 1993). There were also no differences in the way that flush medians and TWLTLs function on rural 4L roads. They recommended the use of flush medians only on highways where the frequency and spacing of driveways permit individual median openings at each driveway. In cases where this is not possible, they recommended the use of TWLTLs on 4L rural highways. Note, TWLTLs are also considered as flush medians. In this reference, the width of flush medians is not specified.

Oklahoma DOT recommends the consideration of TWLTLs in urban and suburban areas, when there is a large number of driveways per mile (> 45 driveways total per mile on both sides), there is a commercial area with high left-turn volumes, and the ADT is between 10,000 and 25,000 (ODOT, 2019).

Georgia DOT has recommendations for TWLTLs in urban and suburban areas (GDOT, 2019c; GDOT, 2019d). The TWLTLs would be recommended when design speeds are 45 mph or lower, and current ADT is less than 18,000 or future ADT is less than 24,000 vpd. Research data showed that after the construction of TWLTLs, the roadway capacity increased by 30%, delay decreased by 30%, and traffic crashes decreased by 35%.

South Carolina DOT recommends TWLTL for 45 mph facilities with four or less lanes, when there are 10 to 35 driveways per mile on both sides of the road, in high-density commercial areas with substantial mid-block left turns. The TWLTLs could be recommended for rural highways, but they are typically near suburban areas or roads passing through small towns. Median width less than 12-feet was not recommended where posted speeds are greater than 35 mph and the percentage of trucks, buses and recreational vehicles is greater than 5 percent of the AADT (SCDOT, 2019).

Idaho DOT considered TWLTL when AADT is equal to or less than 28,000 vehicles per day in urban or suburban areas. The TWLTLs should only be considered in places where commercial driveways are the majority of driveways along a road section and the percentage of vehicles turning left at peak hours is at least 20%. The TWLTLs should not be used in areas that are expected to remain rural in the foreseeable future, or on roadways with posted speeds in excess of 45 mph. In urban and suburban applications, the reduction in left-turn and rear-end crash rates may be as much as 35%. The crash reduction in rural applications is not as dramatic, but if properly used at higher crash locations, the TWLTLs may result in significant safety benefits (ITD, 2019).

Researchers

Fitzpatrick and Blake (1995) evaluated operational and safety differences between flush medians and TWLTL medians on 4L rural roads. They found no differences in these two median types at lower driveway densities. However, their study sites are very limited (Fitzpatrick and Balke, 1995). Note, TWLTLs are also considered as flush medians. In this reference, the width of flush medians is not specified.

Gattis et al. (2005) examined the effects of median treatment and access density on safety outcomes on rural and suburban 4L highways in Arkansas. With an increase in median width (up to 60 to 80 ft), the crash rate decreased while with an increase in access density, the crash rates increased. Their study recommended depressed medians if the access point density is less than 20 and TWLTL if the access point density is greater than 40. Between 20 and 40, a narrow median is recommended (Gattis et al., 2005).

Phillips (2004) compared four-lane median divided highways with TWLTLs. They applied several filters to the data to study suburban settings (Phillips, 2004). Figure 2 summarizes the majority of their results.

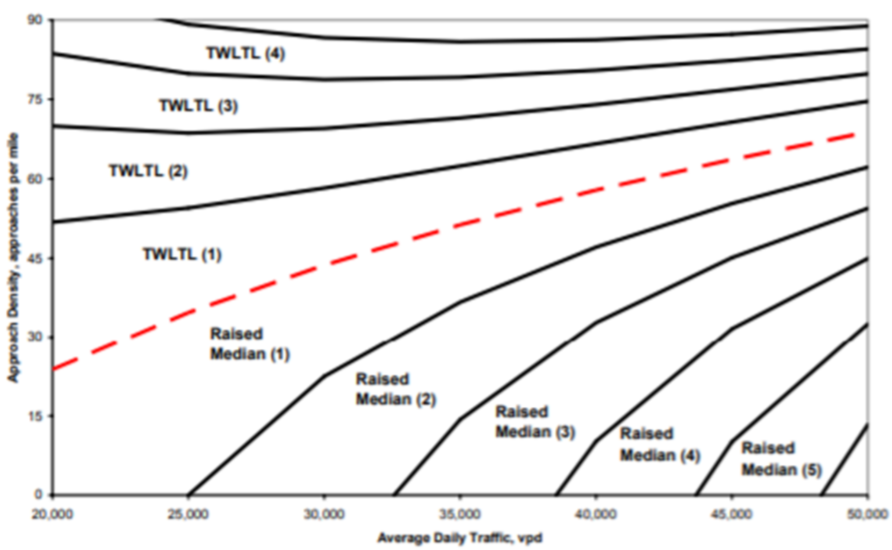


Figure 2. Collision difference for varying ADT and approach density (Phillips, 2004).

The NCHRP report 794 “Median Cross-Section Design for Rural Divided Highways” provided additional criteria (see Figure 3 and Figure 4) based on operation cost savings and accident cost savings (Graham et al., 2014):

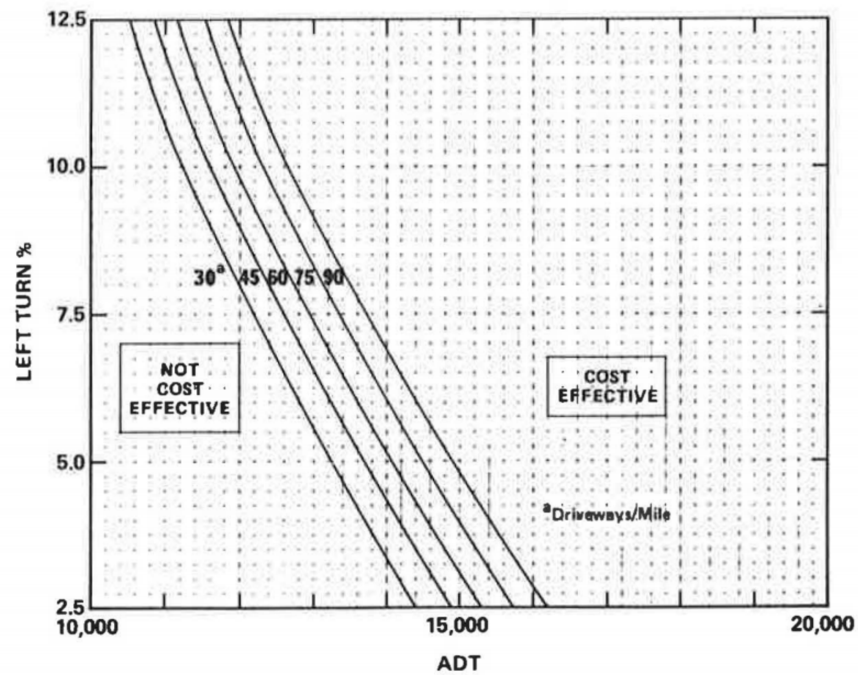


Figure 3. Cost-effectiveness of TWLTL based on operation cost savings (Graham et al., 2014).

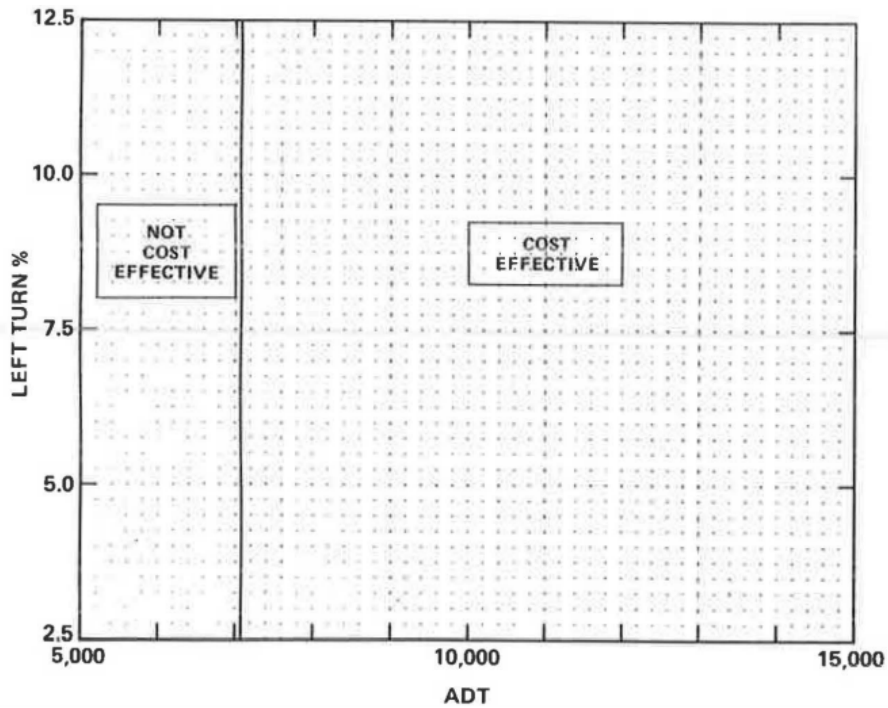


Figure 4. Cost-effectiveness of TWLTL based on accident cost savings (Graham et al., 2014).

After a thorough literature review, it was clear that traffic volume, access point density, truck percentage, turning volume, and spacing of access points are key factors that influence safety on 4L roads besides median type. In summary, there is more information available in the literature for the TWLTLs, NTM, and UR than for the 4FM. Besides, according to our literature search, limited information is available for rural areas compared to urban or suburban areas. We provided Table 1 as a summary of highly relevant studies for rural 4-lane roadways compared to urban or suburban roadways.

Table 1. A summary of highly relevant studies for rural as well as urban/suburban 4-lane roadways.

Title	Study location (State or City)	Rural / urban / suburban	Median type			Guidance criteria				
			4-ft flush median	TWLTL	Other median types	Traffic volume (ADT - vehicles per day)	Vehicle per hour (vph)	Left turn volume or percentage	Access points per mile	Intersection density
Highway safety manual 2010/2011 Edition	--	Suburban	Yes	Yes	--	AADT of 15,000 or more	--	--	--	--
Two-way left-turn lane guidelines for urban four-lane roadways (McCoy et al., 1988).	Nebraska	Urban	--	Yes	--	Cost-effective: >6,200 ~ 6,600 Cost savings: 10,500 ~16,200 Accident cost savings alone: >7100	--	--	--	--
Continuous raised medians	Iowa	Urban	--	Yes	--	10,000~ 28,000	--	--	--	--
Empirical collision model for 4-lane median divided and 5-lane with TWLTL segments	--	Urban	--	Yes	--	--	--	--	25 ~ 90	--
Safety issues related to TWLTL (TWLTL FDOT)	Florida	--	--	Yes	--	--	--	--	--	--
A policy on geometric design of highways and streets 2011	--	Urban	--	Yes	--	--	--	--	--	--
TWLTL - four-lane roadway study_8-9-10 undivided four-lane roadway safety review	Alabama	Urban & Rural	--	Yes	--	--	Peak hour volume > 1750 & < 2400 vph	High	--	--
Continuous two-way left-turn lanes (TWLTLs)	--	Urban & suburban	--	Yes	--	In excess of 10,000 ~ 12,000	--	--	--	--
Accident comparison of raised median and two-way left-turn lane median treatments (Squires and Parsonson, 1989)	Georgia	Urban	--	Yes	--	--	--	--	>75	Unsignalized intersections: maximum of five or six depending on signals per mile

Evaluation of flush medians and two-way, left-turn lanes on four-lane rural highways	Lufkin, Texas	Rural	Yes	Yes	Raised (or depressed) medians,	--	--	--	--	--
Evaluation of flush medians and two-way, left-turn lanes on four-lane rural highways	Nacogdoches , Texas	Rural	Yes	--	--	--	--	--	--	--
Kentucky median type guidance: white paper	Kentucky	Urban & Suburban	Yes	Yes	--	<24000 for TWLTL	--	<100	10 ~ 85 for TWLTL; >10 for flush median	--
Effects of rural highway median treatments and access	Arkansas	Rural & Suburban	Yes <8ft	Yes	Depressed median; Raised median; Barrier; Wide flush median; Narrow flush median	--	--	--	<20 for depressed median; 20 - 40 for narrow median; >40 for TWLTLs	--
Roadway design manual section 3: suburban roadways	--	Suburban	--	Yes	Raised median	6,000 for an existing four-lane suburban roadway	--	--	6 or more	--
Benefits of installing medians	Georgia	Urban & suburban	--	Yes	--	Current traffic volume of < 18,000 & Future traffic volume projected at < 24,000	--	--	--	--
Addition to road design manual four-lane vs. five-lane Comparison/Recommendation	--	Rural	--	Yes	4-lane undivided 4-lane divided 5-lanes	Curbed: DHV<1,000vph ADT<30,000vpd 10' Shoulders: DHV<1,000vph	Curbed: 45 mph or higher 10' Shoulders:	--	>45	>4 intersections/mi

					with TWLTL	ADT<20,000vpd	55/65 mph			
Roadway Design Manual Chapter 7: Cross section element	--	--	--	Yes	--	--	--	--	10 to 35 on both sides of the street	--
Iowa Department of Transportation's Design Manual	--	--	--	Yes	--	17,000-24,000	--	--	--	--
An Evaluation of Flush Medians And Two-Way, Left-Turn Lanes on Four-Lane Rural Highways	--	--	Yes	Yes	Raised or depressed median; flush median; TWLTL	--	--	--	--	--
Design Guidelines for Provision Of Median Access on Principal Arterials	--	Urban	Yes	Yes	Raised median	≥ 24,000	> 45 mph	--	--	--
Road Diet information guide (Knapp et al., 2014)	--	--	--	Yes	--	<20,000	--	--	--	--
Median Cross-Section Design for Rural Divided Highways	--	Rural	Yes	--	--	Base < 18,000 Design = 24,000	--	--	--	--
Practical Solution for Highway Design	--	Rural & Urban	--	Yes	--	< 28,000	--	< 20%	--	--
Safety Evaluation of Installing Center Two-Way Left-Turn Lanes on Two-Lane Roads (Persaud et al. 2008)	Arizona, California, Illinois, North Carolina	Rural	--	Yes	--	--	--	--	--	--

Notes: "--" = not available.

Chapter 3: DATA & METHODS

This chapter details the specifics of all the data that was used for the study and also statistical methods adopted. Table 2 summarizes the data the team has obtained, reviewed and processed.

Table 2. Data procured.

Data	Source	Use of the data
2013-2018 Traffic crash data	GDOT	To obtain crash frequencies by type and severity at sites of interest.
2013-2018 Traffic count data	GDOT	To provide exposure information in safety analysis and SPF development.
TWLTL layer data (shapefile)	GDOT	To identify roadway segments with TWLTLs.
Mileposts of 4FMs and TWLTLs	GDOT	To show locations for 4-ft flush medians and TWLTLs.
Highway Performance Monitoring System (HPMS) data	FHWA website	To identify additional locations for 4-ft flush medians and TWLTLs.

Traffic Crash Data

The crash data provide details about crashes that occurred on Georgia roads from 2013 to 2018. The dataset contains over 130 variables related to persons/vehicle occupants, vehicles, and crashes. All crashes are geo-referenced with longitudes and latitudes, except a smaller portion of crashes missing the geocodes. The geo-references are critical for this project, to link the crashes to roadway segments of focus. Therefore, crashes that are not linked to the segments of interest are out of the project scope and are not be included in the safety performance analysis.

Traffic Count Data

The team obtained traffic count data from GDOT for all stations from 2013-2018. The data were downloaded from the website: https://gdottrafficdata.drakewell.com/publicmultinodemap.asp. Figure 5 shows an example of the data. Variables that are available in the dataset include: station

ID, functional class, latitude and longitude, AADT for each year from 2013 to 2018, Truck percentage for each year from 2013 to 2018. The traffic count data can be linked to the roadway segments with Station ID or the geo-references (i.e., longitude and latitude). Figure 6 shows an example of the 2018 traffic counts on Georgia roadways. The data look reasonable, as high-volume roads appear to be in urban areas, especially in the metropolitan area of Atlanta.

Station ID	Functional Class	Lat/Long	Lat	Long	AADT_ 2018	Truck% _2018	AADT_ 2017	Truck% _2017	AADT_ 2016	Truck% _2016	AADT_ 2015	Truck% _2015	AADT_ 2014	Truck% _2014	AADT_ 2013	Truck% _2013
001-0183	4R : Rural M	31.831560	31.83156	-82.0865	970	18.7	990	18.2	940	18.2	880	18.1	850	19.2	870	16.4
001-0185	5R : Rural M	31.602850	31.60285	-82.3082	410	11.7	450	16	480	17.7	490	17.8	480	17.7	520	15
003-0132	3R : Rural P	31.307110	31.30711	-82.9015	4760	22.9	4660	23.5	4600	23.5	4550	23.7	4360	24.5	4360	23.6
003-0138	3R : Rural P	31.295800	31.2958	-82.8398	4520	23.1	4470	23.6	4390	23.7	4310	21.7	4170	24.4	4110	24.7
005-0125	3R : Rural P	31.608610	31.60861	-82.4619	5380	16.4	5300	17	5140	17.3	4840	19	4620	19.7	4480	19.6
009-0156	4R : Rural M	33.086990	33.08699	-83.1722	8030	7.4	8410	6.7	9190	8.7	9070	9.2	8710	8.6	8610	8.1
011-0103	3R : Rural P	34.279330	34.27933	-83.4653	13900	7.9	13700	7.4	12700	7.4	12000	7.4	11300	7.4	10900	7.1
013-0036	4U : Urban I	33.977490	33.97749	-83.6533	8190	5.9	8180	6.1	8300	5.8	8110	5.5	7860	5.2	8090	4.2
015-0118	3U : Urban F	34.204360	34.20436	-84.8105			45200		44900	4.9	43600	4.9	42200	4.9	41500	5.7
015-0178	3U : Urban F	34.214850	34.21485	-84.7942	10300	8.5	10600	9.4	10800	9.1	9870	9.1	9480	9	9370	8.3
015-0276	1U : Urban F	34.218710	34.21871	-84.7522	78700	25.6	78600	22.5	75200	21.4	73600	24.5	70700	24.5	66600	17.9
017-0143	3U : Urban F	31.728930	31.72893	-83.2472	3480	4.7	3410	6.7	3470	6.6	3420	6.3	3410	6.4	3510	5.7
021-0116	4R : Rural M	32.806320	32.80632	-83.8409	4080	7.1	4110	7.1	4310	6.8	4200	6.5	4240	6.7	4360	6.6
021-0132	3U : Urban F	32.815970	32.81597	-83.7028	19900	4.1	20300	4.3	20800	4.1	20900	4.1	20800	3.8	21300	3
021-0158	3U : Urban F	32.736130	32.73613	-83.6557	28100	6	28000	7.5	27600	7	26500	7	25400	7.2	25600	7

Figure 5. Traffic count data example.

Roadway Data

GDOT provided two datasets that were used to extract the roadway-related information: 1) Layer data of TWLTL routes in Georgia; and 2) Mileposts of existing 4FM and TWLTLs (reported by GDOT Districts). In addition to GDOT-provided data, the team utilized the publicly available roadway data from the Highway Performance Monitoring System (HPMS) to identify more segments that fit into the project scope. The data can be downloaded from the Federal Highway Administration (FHWA) at https://www.fhwa.dot.gov/policyinformation/hpms/shapefiles.cfm. The HPMS data are in shapefile format and contain a comprehensive list of roadway attributes for all public roads in the country, including the median type and median width information, traffic volume data (AADT and truck volume) and number of lanes.

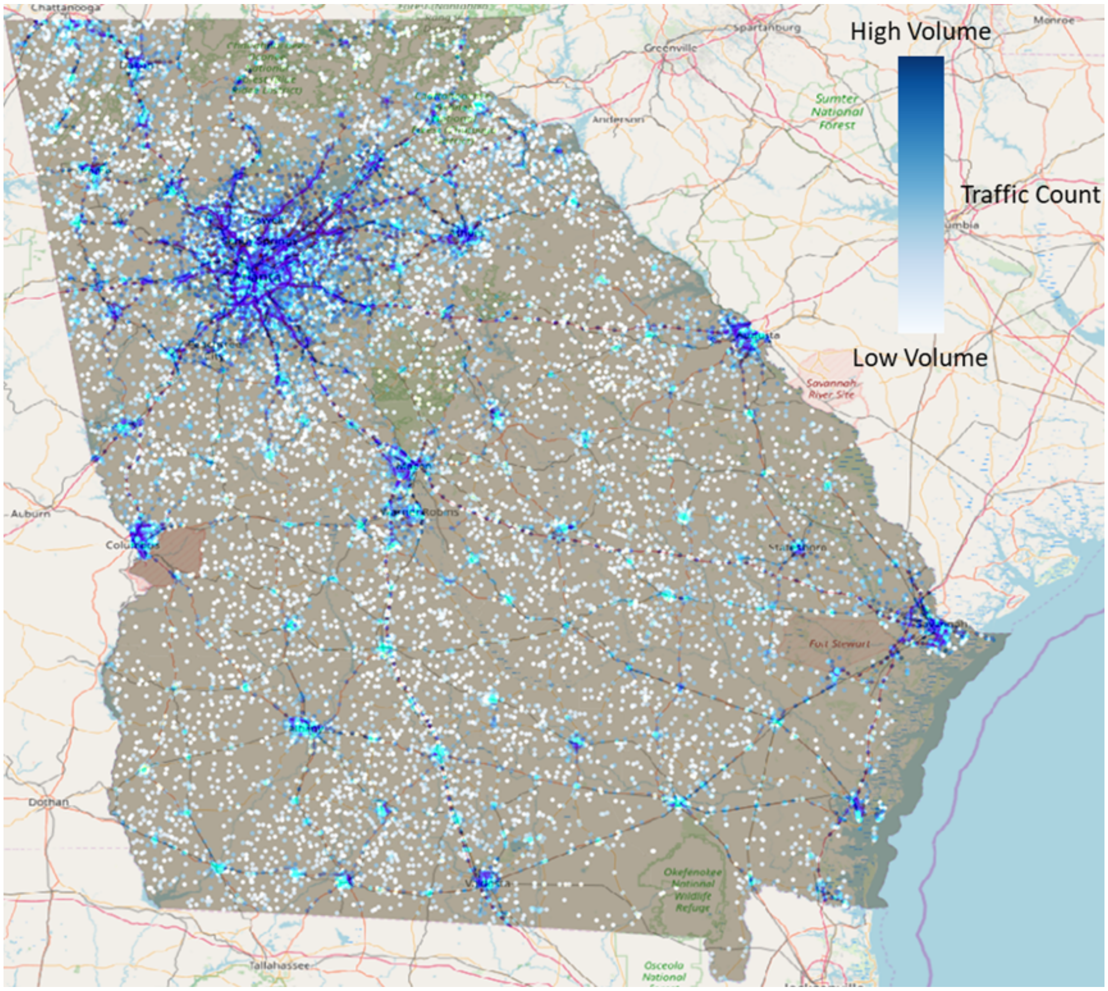


Figure 6. Traffic count data example.

Figure 7 shows the HPMS data visualized in a Geographic Information System (GIS) platform. In addition to GDOT-provided data, the team looked into HPMS data to identify additional segments. Due to some extent of the data inaccuracy and missing information for some segments in the HPMS data, the project team carefully examined the HPMS data. First, according to the HPMS variables, segments that are clearly not within the project scope (rural four-lane segments with speed limit 50 mph or higher) are not included in the analysis. Only segments that are in rural areas, with four-lanes and high-speed limits (i.e., 50 mph or higher) are kept. We used the same characteristics (rural or urban, number of lanes, posted speed limit) to remove segments out of the project scope and keep the ideal segments for this project. Then, the project team used Google Maps to manually check these locations, and only verified segments are merged into the shapefiles for four median types detailed in the following sections.

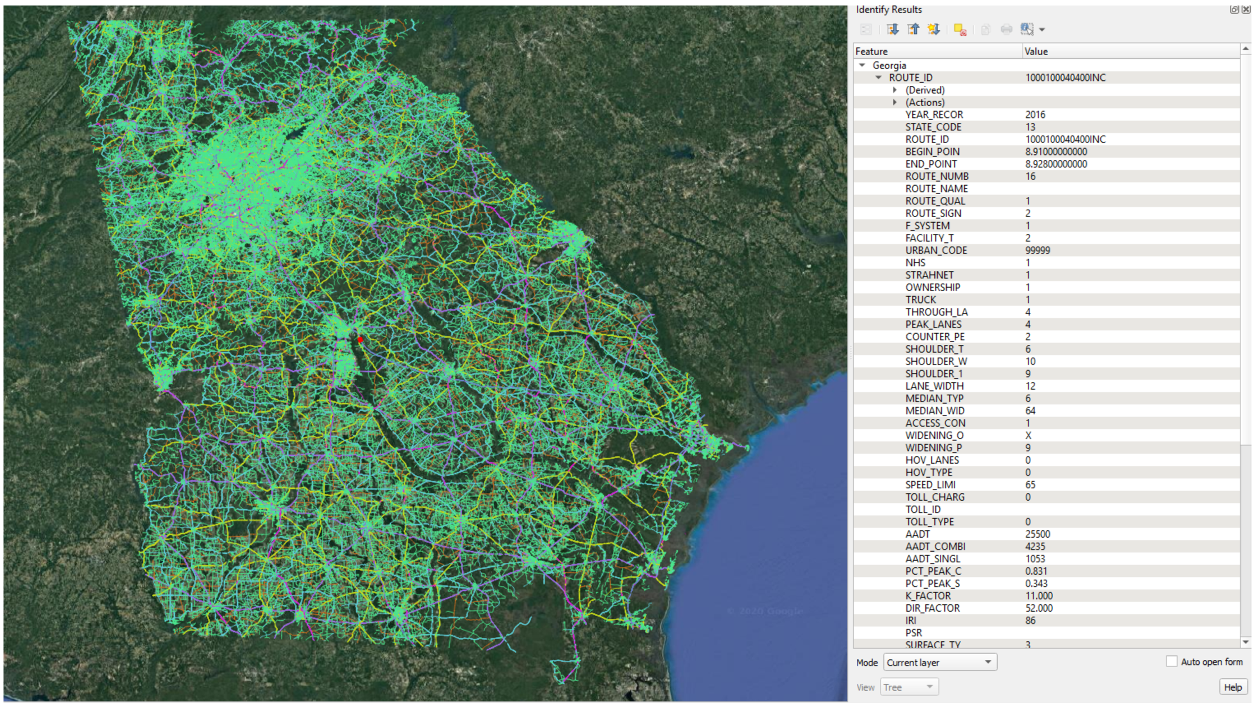


Figure 7. HPMS data.

Undivided roadway segments

Given the potentially similar safety performance of rural 4L roads with flush median width less than 3 ft, these roads are considered as UR for this study. Figure 8 exhibits examples of rural four-lane undivided roadways and the statewide identified undivided roadway segments.

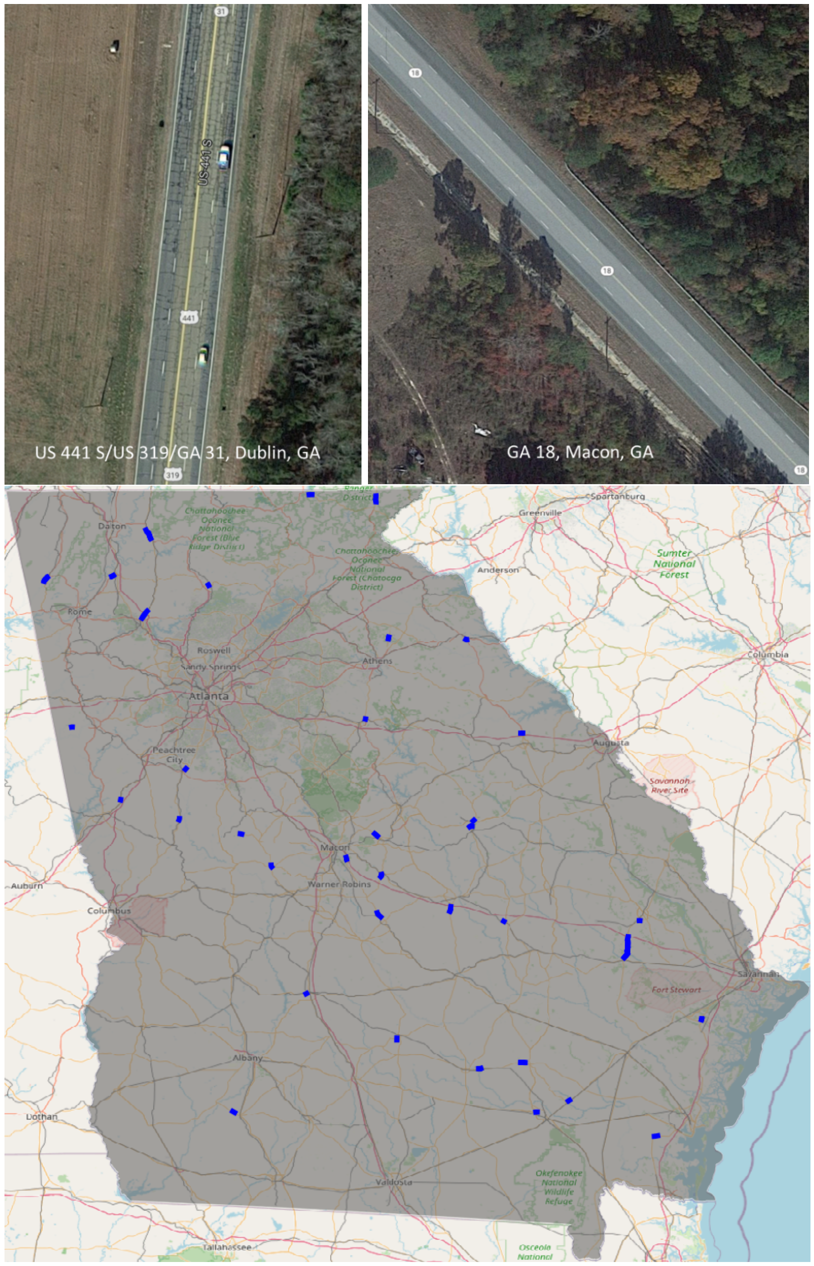


Figure 8. Examples of rural four-lane undivided roadway and identified locations of rural four-lane undivided roadways segment.

4-ft Flush Medians

If the flush median width is roughly between 3 and 5 feet, we considered it a 4-ft flush median (divided roadway). The team manually verified GDOT provided 4L roads with 4FM using Google

Maps. A shapefile was created to document the verified roadways with 4FM. In addition, the team looked into the HPMS data to identify any additional segments. Figure 9 exhibits examples of rural four-lane 4-ft flush median roadways and the statewide identified 4-ft flush median roadway segments.

Figure 9. Examples of rural four-lane 4-ft flush median roadway and identified locations of rural four-lane 4-ft flush median roadways segments.

TWLTLs

The same segment identification method was used to locate the rural four-lane TWLTL segments in Georgia. Figure 10 exhibits examples of rural four-lane TWLTL roadway and the statewide identified TWLTL roadway segments.

Figure 10. Examples of rural four-lane TWLTL roadway and identified locations of rural four-lane TWLTL roadways segments.

Non-traversable

Using the same segment identification method, the project team was able to locate the rural four-lane non-traversable segments in Georgia. Figure 11 exhibits examples of rural four-lane non-traversable roadway and the statewide identified non-traversable roadway segments.

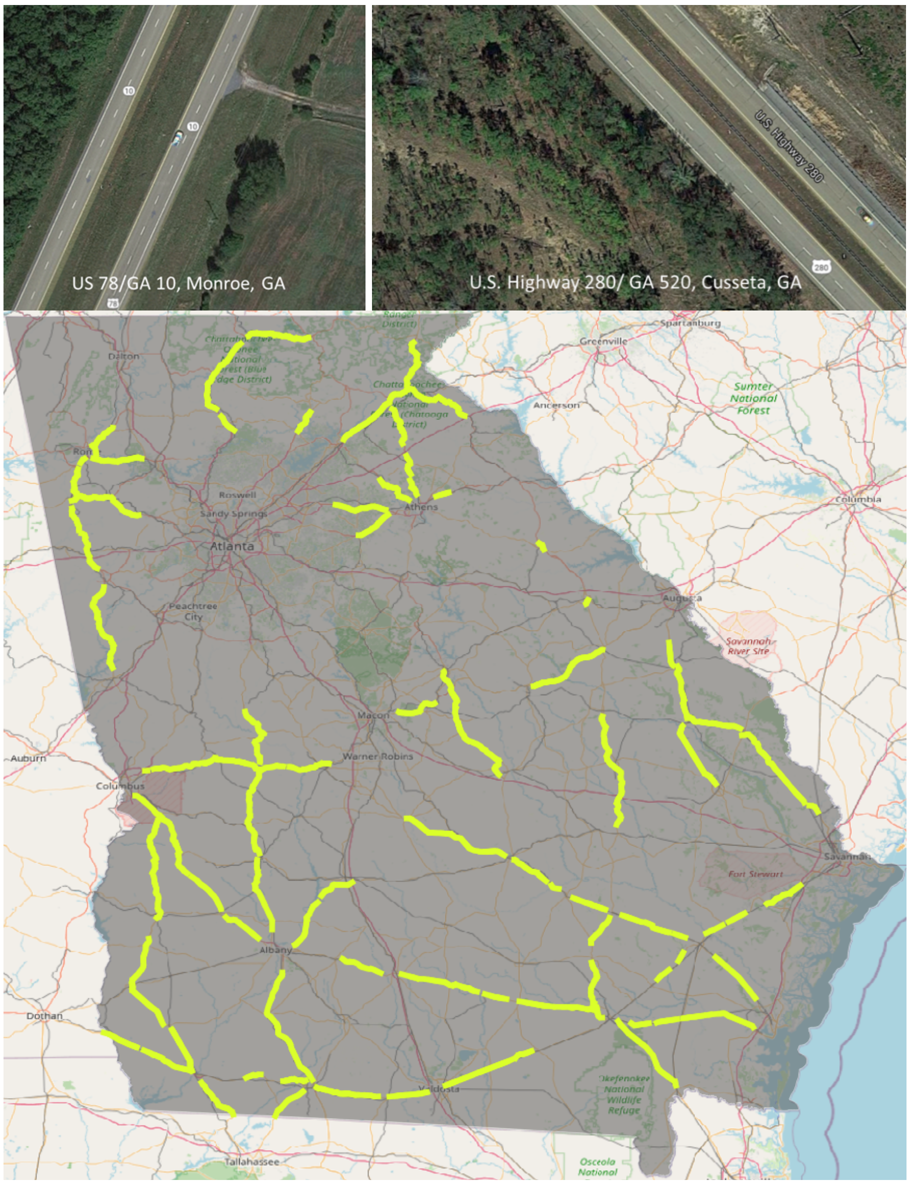


Figure 11. Examples of rural four-lane non-traversable roadway and identified locations of rural four-lane non-traversable roadways segments.

After data cleanup, there were four different shapefiles for the four interested median types on 4L roads including undivided, 4-ft flush median, TWLTL, and non-traversable. The shapefiles consisted of road segments that are as short as 0.001miles and as long as 6.137 miles. Hence, before developing SPFs, it is necessary to refine this data by creating homogenous roadway segments that have similar road characteristics. The research team manually looked up the characteristics of roadways within the shapefile using Google Maps and QGIS tools. Shorter segments were merged with adjacent segments if they had similar features. Similarly, a homogenous longer road segment was divided into shorter segments if major intersection (i.e., signalized four-leg intersections) were identified, particularly for non-traversable segments. Major intersections (i.e., signalized four-leg intersections) are used as slicers to dissect longer road segments into shorter ones.

Subsequent to all the merges and splits, a shapefile was created with homogeneous road segments to help with the rest of the data analysis. According to the HSM 2010, the desirable minimum sample size for the calibration database for one predictive model is 30 to 50 sites. For segments, each site should be between 0.1 and 1.0 mile in length. Lengths in this range should be long enough to have statistical validity and short enough to be realistically homogeneous (AASHTO, 2010). Note that some segments are relatively short because they are isolated in the rural areas and cannot be linked to other segments, though HSM recommends the minimum length is 0.1 miles. Similarly, some rural segments are longer than 1 mile, because they are homogeneous in the sense that they cannot be divided into shorter segments by major intersections or other traffic controls. All segments are high-speed rural 4-lane segments, greater than 45 mph. Table 3 shows descriptive data statistics of the homogeneous road segments created in terms of segment length.

Table 3. Frequency of homogeneous segments for safety analysis by segment length.

Length (miles)	UR	4FM	TWLTL	Non-traversable
0.09 - 0.19	9	14	109	5
0.20 - 0.49	39	80	263	158
0.50 - 0.99	23	51	150	431
1.00 - 1.99	7	18	33	458
2.00 - 6.14	1	2	3	124
Average Segment length	0.529 (miles)	0.555 (miles)	0.444 (miles)	1.151 (miles)

Access Points

The number of access points is an important parameter for this study. However, there is no existing database that provides such information. Hence, the research team extracted the number of access points for each identified road segment by using Google Maps. Major intersections were used to separate long segments, and only minor intersections and driveways are counted towards the total access points along a segment. Figure 12 shows a screenshot of how access points were counted. The descriptive data statistics of the access point density variable are detailed in Chapter 4.

Data Linkages to Segments

Finally, the team linked the crash records (from 2013 to 2018) and traffic volume to sampled segments based on the geo-references (i.e., longitudes and latitudes). The latitude and longitude in the crash data were used to locate crashes; GIS shapefiles were created for the crashes from 2013 to 2018. Not all latitude and longitude information were valid in the crash datasets; therefore, crashes with invalid latitude and longitude information (e.g., null latitude and longitude, (-1, -1), (44.956954, -69.937925)) are removed from the datasets (less than 0.5% of the total sample).

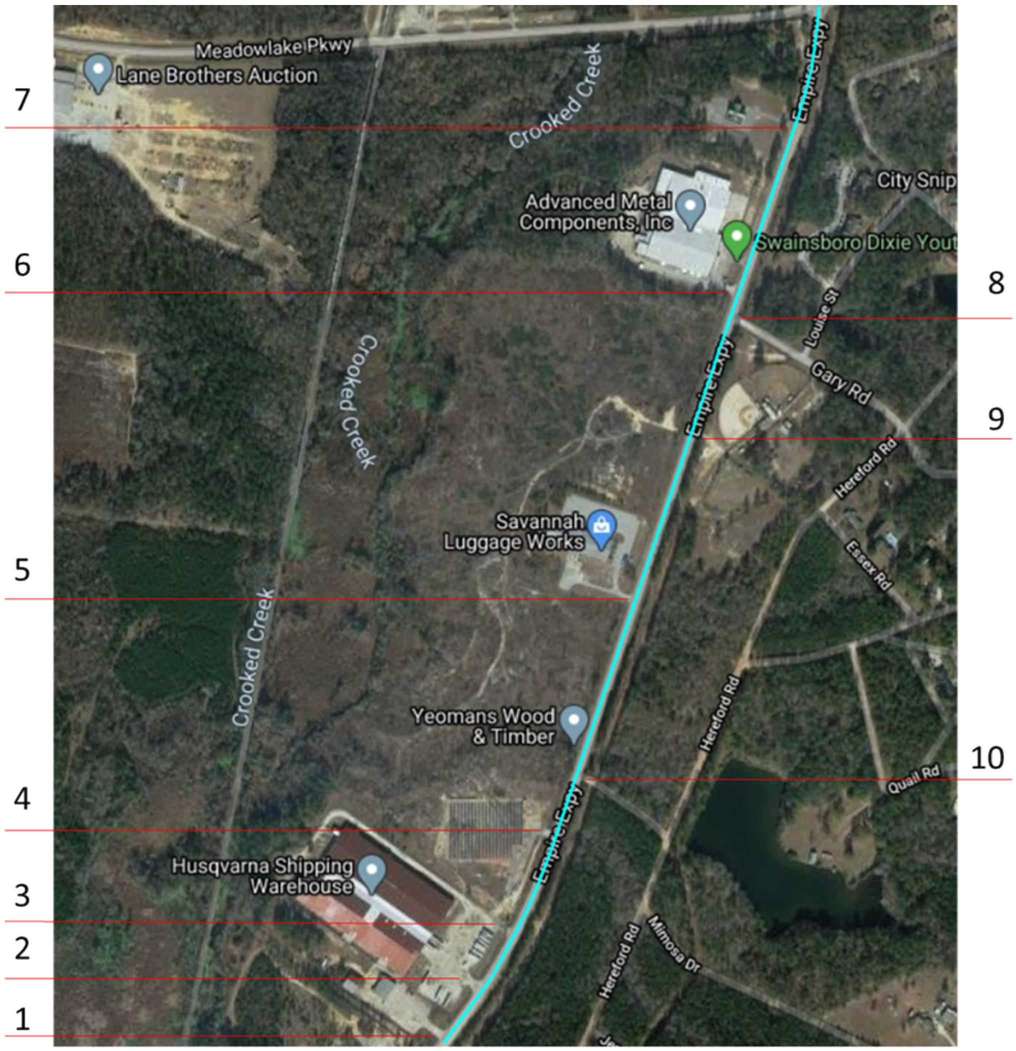


Figure 12. An example of counting the access points along a sampled roadway segment.

There are a few crashes that did not fall exactly on the roadway (within the right-of-way), but were close to the sampled segments. For such crashes, the research team verified the road name, road class, and other information that can help locate the crash, to make sure crashes are correctly linked to the sampled segments. A small number of crash records do not contain the geo-reference information. It remains unknown how many of these crashes are related to the sampled segments in this study. The statistics presented in this report might be underrepresented given this common issue, which is not unique to this study. The homogeneous roadway segment shapefile and crash data shapefile were overlaid; crashes were geographically linked to roadway segments, as shown in Figure 13. Figure 14 shows examples of data linkage results - crashes that occurred on sampled road segments.

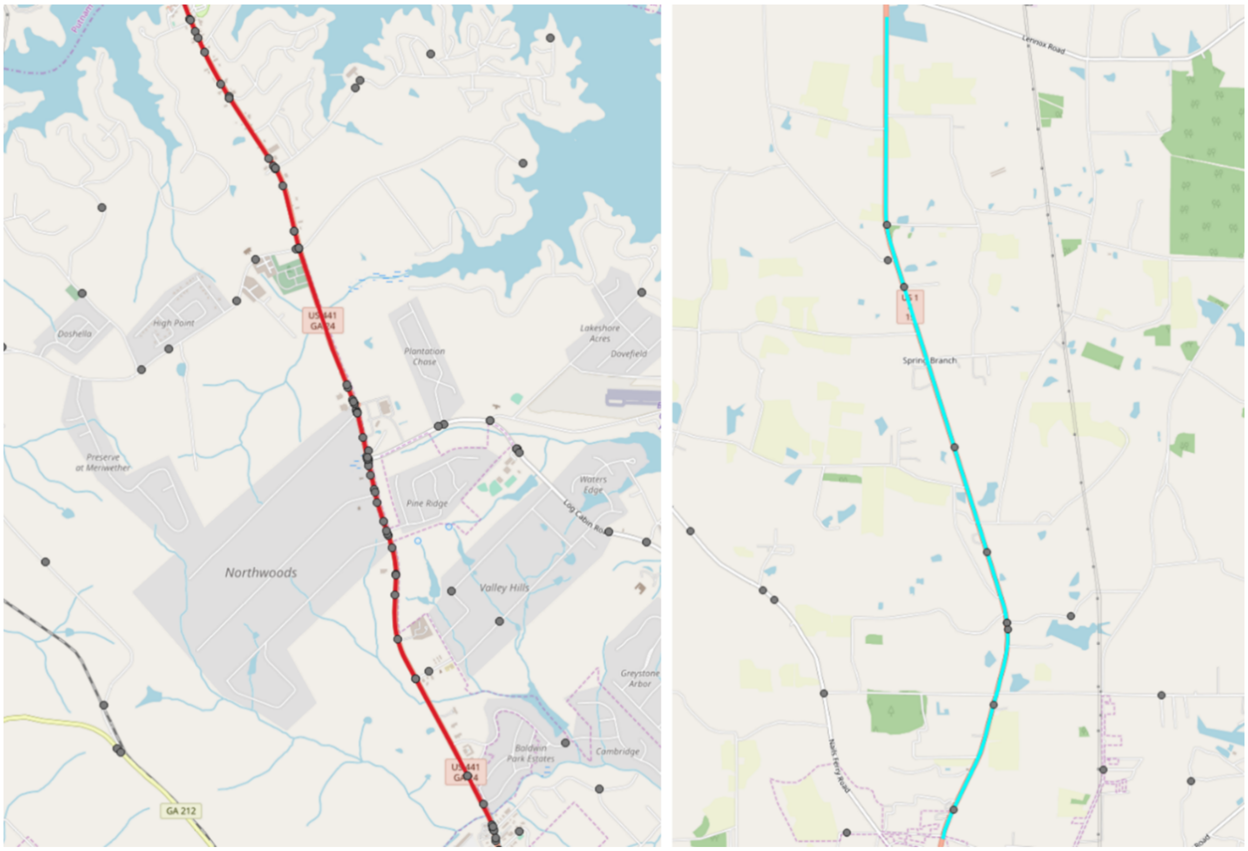


Figure 13. Examples of overlaid homogeneous TWLTL roadway segment with 2018 crash data (Left); and overlaid homogeneous 4-ft Flush Median roadway segment with 2018 crash data (Right) before the linkage. (Grey dots represent the crashes)

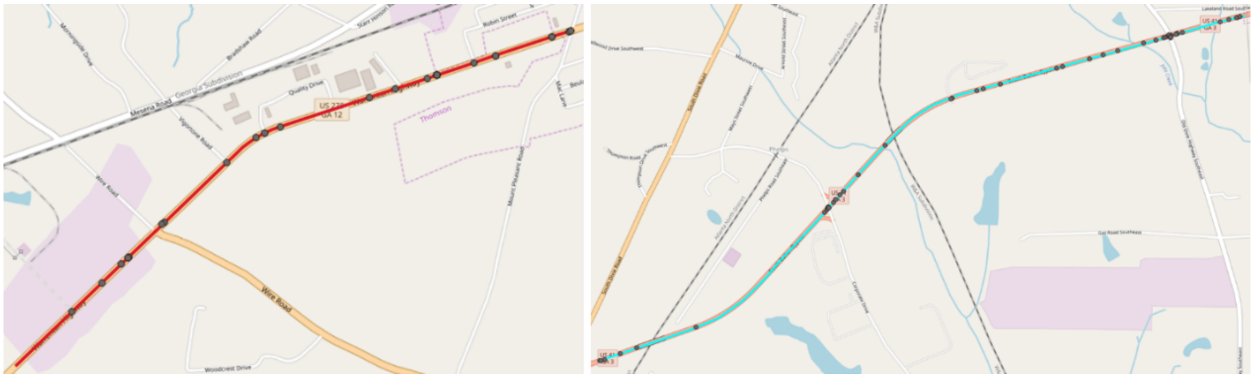


Figure 14. Example of overlaid homogeneous TWLTL roadway segment with all crash data (Left); and overlaid homogeneous 4-ft Flush Median roadway segment with all crash data (Right) after the linkage. (Grey dots represent the crashes)

Similarly, the AADT stations were also linked to sampled segments using the same near analysis method to obtain the AADT information for sampled roadway segments. Figure 15 presents the AADT stations that are located in the sampled roadway segments. We do acknowledge that some of the segments do not have an associated AADT. We used AADT along the nearby segments to interpret an AADT value in these cases.

For the final safety analysis, four different shapefiles for four different median types (UR, 4FM, TWLTL, NTM) were created that have traffic volume, truck percentage, access points, segment length, and number of crashes by severity information.

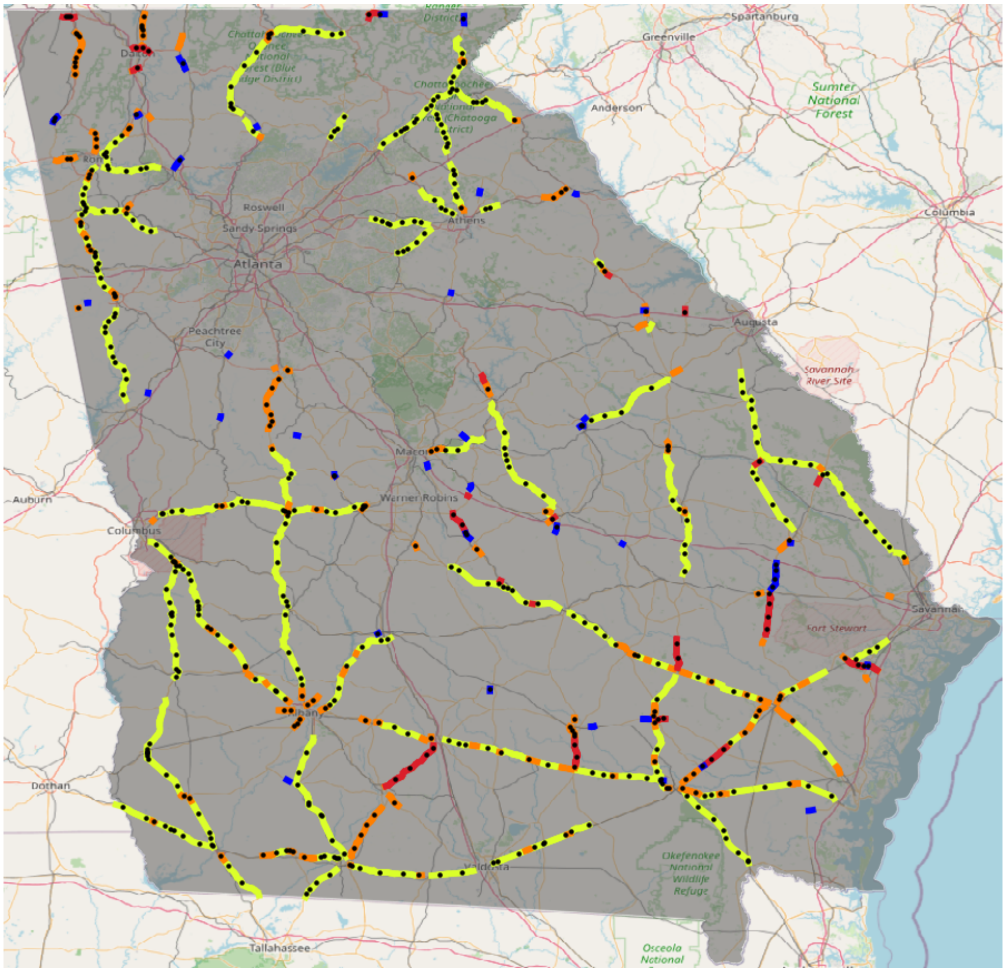


Figure 15. Spatial distribution of AADT stations (black dots) that are linked to the sampled roadway segments.

Modeling Background

According to the HSM, the standard or most common form of an SPF for roadway segments is described as below (AASHTO, 2010):

$$N_{SPF} = L \times e^{a + b \times \ln(AADT)} \quad \text{or} \quad N_{SPF} = e^{a + b \times \ln(AADT) + \ln(L)} \tag{1}$$

where N_{SPF} is the predicted number of crashes on a segment; L is the length of the segment; $AADT$ is annual average daily traffic volume; a and b are regression coefficients to be estimated using historical crash data. In Equation (1), the segment length L is included as a multiplier, which assumes that the crash frequency on a segment is simply proportional to the segment length. However, this assumption may be inappropriate in some cases. Traveling on a road segment, a driver experiences homogeneous road conditions (including the number of lanes, the shoulders, etc.). Driving on a relatively longer road segment with unchanging circumstances may be different from driving on a relatively shorter road segment with frequent variations of circumstances. Therefore, another common form of SPFs is also suggested by transportation professionals:

$$N_{SPF} = \mathrm{e}^{a + b \times \ln(AADT) + c \times \ln(L)} \tag{2}$$

where c is a parameter indicating the relationship between crash frequency and segment length. If the estimate of *c* is close to 1, then Equation (2) is identical to equation (1). If *c* is significantly different from 1, then it shows that the road segment length is not simply proportional to crash frequencies.

Multiple regression models are estimated, providing parameters (*a*, *b,* and *c*) of the SPFs. It is assumed, in the HSM, that crash frequencies follow a negative binomial (NB) distribution (AASHTO, 2010). The negative binomial distribution is an extension (capturing over-dispersion) of the Poisson model:

$$Y_i \sim NB\left(N_{SPF\,i}, \alpha\right) \tag{3}$$

where Y_i is the observed crash frequency on a segment; $N_{SPF\,i}$ is the expected crash frequency, and α is the NB over-dispersion parameter. A larger value of α implies greater over-dispersion in data. If α = 0, then the data follows a Poisson distribution (where mean = variance). In such a situation, the Poisson and Negative Binomial model provide identical estimates of parameters (*a*, *b,* and *c*). If α is significantly greater than 0, an NB model is preferred. Formally, $N_{SPF\,i}$ can be viewed as a log link function of a set of independent variables (Liu et al., 2017):

$$Ln\left(N_{SPF\,i}\right) = a + b \times \ln\left(AADT_i\right) + c \times \ln\left(L_i\right) \tag{4}$$

In addition to the variables of AADT and segment length in the standard SPF, other factors can also be included in the form. The truck percentage has a complex relationship with the crash frequency due to its intercorrelated relationship with the traffic volume AADT. Figure 16 shows the scatter plot of traffic volumes (AADT) and the truck percentages. Higher truck percentages are more likely to exist in lower traffic volumes. By adding the interaction term in modeling, we can capture the main effect of truck percentages on crash frequencies and also the intercorrelation between the AADT and truck percentage.

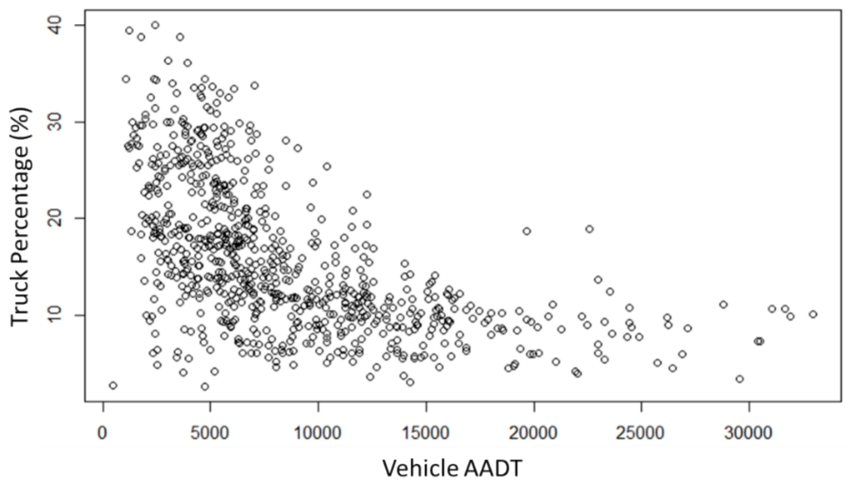


Figure 16. Scatter plot of vehicle AADT and truck percentage.

An expanded SPF form, including the truck percentage and access point density can be expressed as:

$$Ln\left(N_{SPF\,i}\right) = a + b \times \ln\left(AADT_i\right) + c \times \ln\left(L_i\right) + d \times TP_i + e \times APD_i + f \times \ln\left(AADT_i\right) \times \tag{5}$$

where $N_{SPF\,i}$ is the predicted number of crashes on a segment i; L_i is the length of the segment i; $AADT_i$ is annual average daily traffic volume of the segment i; a and b are regression coefficients to be estimated using historical crash data; TP_i is the truck percentage and APD_i is the access point density along a segment i; parameters d and e are the coefficients for truck percentage and access point density; f is a coefficient for the interaction term between truck percentage and AADT.

In recognizing the improved prediction performance of SPFs, the research team applied an advanced random-intercept modeling technique to estimate SPFs. This technique can account for the unobserved heterogeneity that may exist in the model data. Both traditional NB models and random-intercept NB models are estimated. The models can be compared by calculating the Akaike Information Criterion (AIC), which is often reported in statistical applications.

Methodology to Estimate CMFs

When a site or segment is different from the base condition, or a new treatment is added to a segment, the Crash Modification Factors (CMFs) are used to adjust the SPF-predicted crash frequency. A CMF is a measure of the safety effectiveness of a particular treatment or design element. This project developed CMFs for 4FM, TWLTLs, and NTM by comparing the safety performance with the baseline – rural 4L-UR. The CMFs estimated based on the following equation:

$$CMF = \frac{Predicted\ crash\ frequency\ for\ target\ segments}{Predicted\ crash\ frequency\ for\ baseline\ segements} \quad (6)$$

The target segments are the rural 4L roadways with 4FMs or TWLTLs or NTMs; the base segments are the rural 4L-URs. As defined in SPF, the crash frequency is a function of traffic volume (AADT), truck percentage, access point density and segment length. Therefore, CMFs are likely to vary across different values of AADT, segment length, truck percent and access point density, indicating that the safety effectiveness of a treatment on roadways is likely to vary across different situations. The CMFs need to be estimated by controlling all other factors constant (i.e., the same values across different segment types). This study predicted the crash frequencies for one mile of segments. For the other three factors (AADT, truck percent and access point density), their values change simultaneously across all segment types in the CMF estimations.

Chapter 4: DESCRIPTIVE ANALYSIS

Based on the collected and prepared data, the team conducted descriptive statistics analysis on the sampled segments and the results were presented in this Chapter. Furthermore, this chapter presents the dimensions of the data, which help better understand the roadway, traffic, and safety conditions of the sampled segments.

Traffic Crashes

From 2013 to 2018, a total of 1,611,889 crashes were reported on Georgia roadways. On sampled rural 4L roadway segments, there are 24,564 crash records on TWLTL segments, 1,562 on 4FM segments and, 4,973 on undivided segments. Table 4 provides the crash frequency distributions by severity, collision type, road type, number of vehicles involved, and year, respectively. Overall, there are more crashes on the non-traversable roadway segments due to the larger sample of non-traversable roadway segments.

In terms of KABCO injury severity (K – Fatal Injury, A – Suspected Serious injury, B– Suspected Minor or Visible Injury, C – Possible Injury or Complaint, O – No Apparent Injury), the majority of the crashes were no apparent injury (O) crashes (at least 59%). Fatal injury and suspected serious injury crashes (KA) had higher proportions on rural four-lane undivided segments (2.44% and 17.4%, respectively) compared to those of other median type segments.

In terms of the manner of collision for crashes on sampled segments, rural four-lane TWLTL segments had a higher proportion (23.91%) of angle crashes compared to other median type segments. Rural four-lane 4-ft flush median segments had a higher proportion (42.23%) of rear-end crashes; while rural four-lane non-traversable segments had a higher proportion (51.69%) of crashes that were not a collision with other motor vehicles. Note that some manner of collision information was missing for some of the crashes.

In terms of the number of vehicles involved in the crashes on sampled segments, rural four-lane non-traversable segments had a higher proportion of (53.26%) of single-vehicle crashes; while rural four-lane 4-ft flush median and TWLTL segment had higher proportions of multi-vehicle crashes (68.12% and 64.69%, respectively).

The crashes also presented temporal trends along the study period from 2013 to 2018. Results in Table 4 indicate that number of crashes occurred on the sampled segments exhibited an overall increasing trend from 2013 to 2018. Particularly, the number of crashes increased by about 51.7% from 2013 to 2018 for rural four-lane undivided segments compared to that of about 40% for the other three median types of roadway segments. Table 4 also indicates that NTM roadways have the second-highest percentage of fatalities and the highest number of fatalities in the study period. This is most likely the posted speed limit is higher on NTM roadways, which may be a contributing factor to high fatality frequency along NTM roadways (see Appendix A for more details).

Table 4. Crashes statistics for undivided, 4-ft flush median, TWLTL, and non-traversable roadway segments.

Median Type / Crash Features	UR (Freq & %)	4FM (Freq & %)	TWLTL (Freq & %)	NTM (Freq & %)
Total Crashes	615	1,518	4,868	13,694
KABCO				
Fatal Injury	15	18	65	201

(K)	(2.44%)	(1.19%)	(1.34%)	(1.47%)
Suspected Serious Injury (A)	107 (17.4%)	210 (13.83%)	505 (10.37%)	1,968 (14.37%)
Suspected Minor or Visible Injury (B)	66 (10.73%)	188 (12.38%)	506 (10.39%)	1,584 (11.57%)
Possible Injury or Complaint (C)	49 (7.97%)	117 (7.71%)	461 (9.47%)	868 (6.34%)
No Apparent Injury (O)	367 (59.67%)	971 (63.97%)	3,257 (66.91%)	8,942 (65.3%)
Manner of Collison				
Angle	114 (18.54%)	233 (15.35%)	1,164 (23.91%)	1,854 (13.54%)
Head-On	16 (2.60%)	40 (2.64%)	106 (2.18%)	217 (1.58%)
Read-End	149 (24.23%)	641 (42.23%)	1,285 (26.4%)	3,152 (23.02%)
Sideswipe – Same Direction	43 (6.99%)	122 (8.04%)	496 (10.19%)	1,117 (8.16%)
Sideswipe – Opposite Direction	14 (2.28%)	11 (0.72%)	68 (1.40%)	89 (0.65%)
Not a Collision with a Motor Vehicle	267 (43.41%)	451 (29.71%)	1,648 (33.85%)	7,078 (51.69%)
Single / Multiple Vehicles				
Single-Vehicle	281 (45.69%)	484 (31.88%)	1,719 (35.31%)	7,293 (53.26%)
Multi-Vehicle	334 (54.31%)	1,034 (68.12%)	3,419 (64.69%)	6.401 (46.74%)
Year				
2013	87 (14.15%)	235 (15.48%)	738 (15.16%)	2,063 (15.06%)
2014	97 (15.77%)	233 (15.35%)	731 (15.02%)	1,942 (14.18%)
2015	87 (14.15%)	254 (16.73%)	765 (15.71%)	2,053 (14.99%)
2016	104 (16.91%)	253 (16.67%)	771 (15.84%)	2,429 (17.74%)
2017	105 (17.07%)	209 (13.77%)	840 (17.26%)	2,339 (17.08%)
2018	132 (21.46%)	332 (21.87%)	1,023 (21.01%)	2,868 (20.94%)

Notes: Adding the subcategory number of crashes might not be equal to the total number of crashes due to that some of the crashes may have unknown values in those categories (e.g., some category values are coded as 99 or 98).

The per-mile crash frequency is also calculated and aggregated at the segment level for undivided, TWLTL, 4-feet flush median, and non-traversable segments from 2013 to 2018 (see Table 5).

Table 5. Crashes statistics for different median facility types in 2018.

Facility Type / Per mile Crashes Frequency	Frequency of Segments			
	UR	4FM	TWLTL	NTM
0-9	31 (39%)	193 (56%)	238 (43%)	771 (66%)
10-19	29 (37%)	35(21%)	127 (23%)	241 (20%)
20-29	8 (10%)	11 (7%)	77 (14%)	88 (7%)
>30	11 (14%)	26 (16%)	116 (21%)	76 (6)
Average Per mile	15.45	20.97	22.55	11.02
Maximum Per mile	75.19	450.78	472.22	144.15

For sampled TWLTL roadways, the per-mile crash frequency can be as high as 472 crashes per mile. In addition to the descriptive data statistics of the crashes, the research team provided additional spatial distribution of those crashes. Per mile crash frequency (number of crashes per mile) are presented in Figures 17, 18, 19, and 20 for the four types of facilities, including rural four-lane undivided, 4-ft flush median, TWLTL, and non-traversable segments. The visualized results show that sampled rural four-lane segments had diversified per mile crash frequency across the state of Georgia. For example, for sampled 4-ft flush median roadway segments, the per-mile crash frequency was higher in northwest rural areas. Figure 20 shows that sampled non-traversable segments in the segments surrounding big cities (i.e., Atlanta) seem to have a greater per-mile crash frequency.

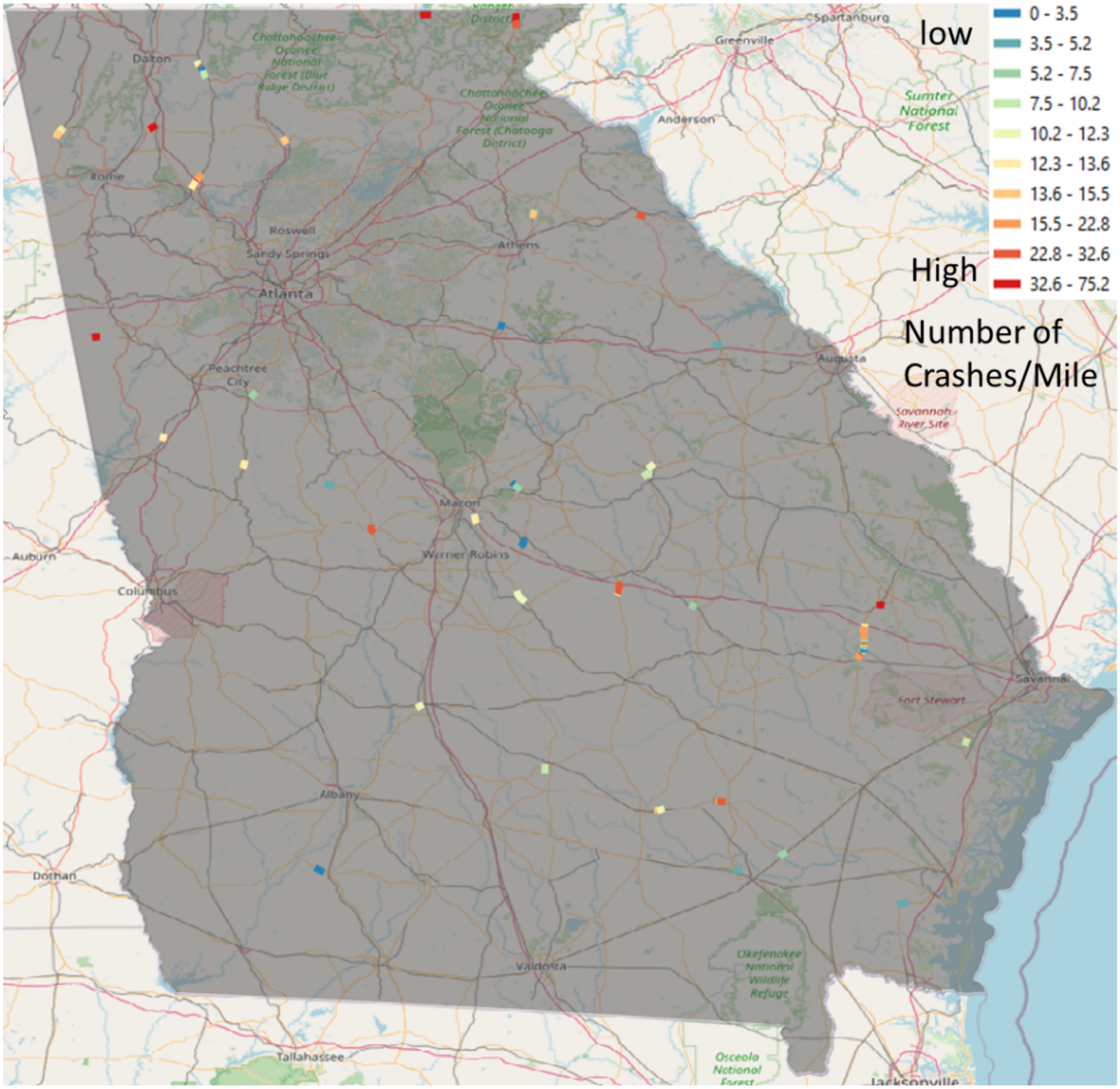


Figure 17. Number of crashes per mile along the rural four-lane undivided segments.

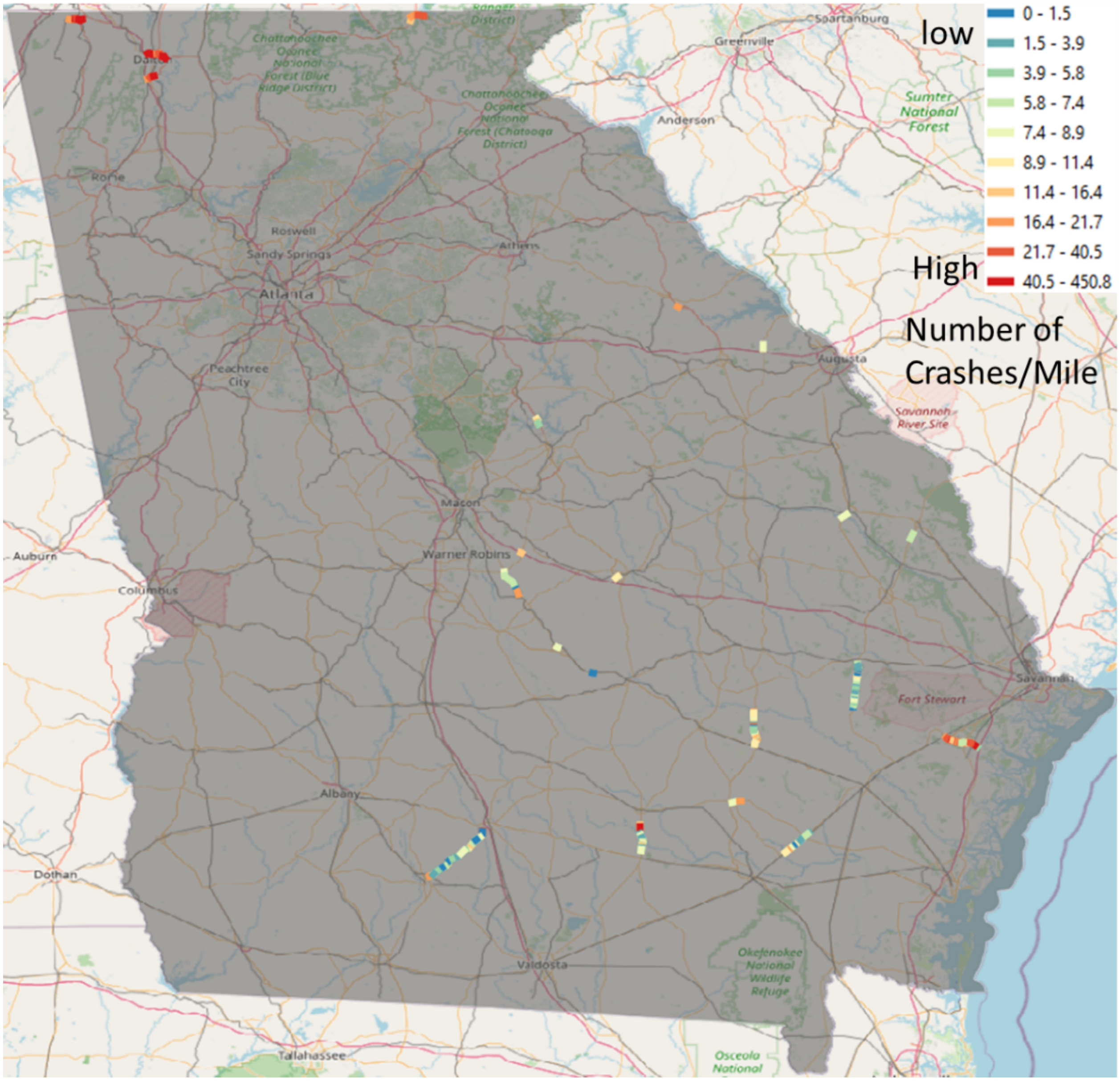


Figure 18. Number of crashes per mile along the rural four-lane 4-ft flush median segments.

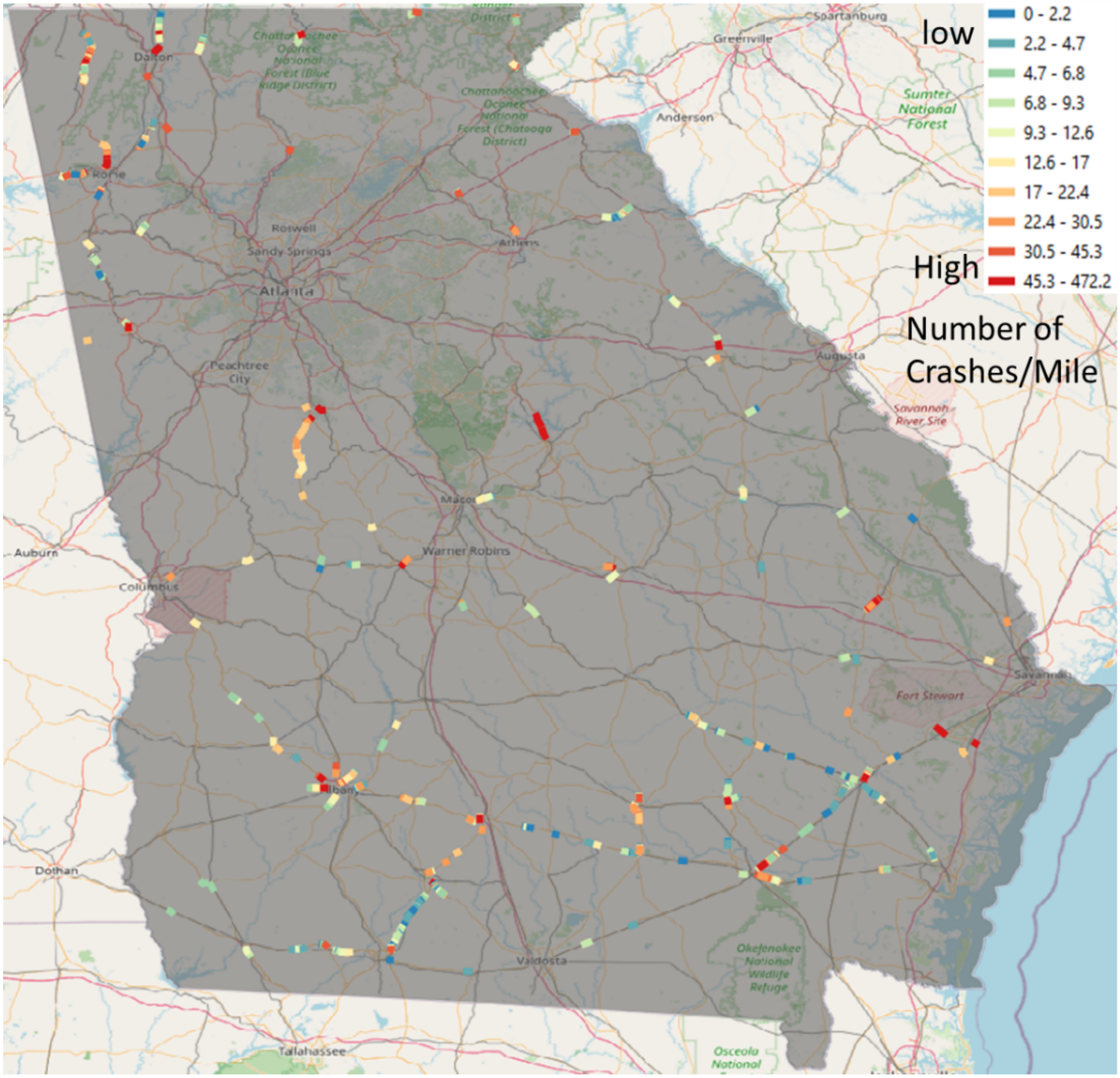


Figure 19. Number of crashes per mile along the rural four-lane TWLTL segments.

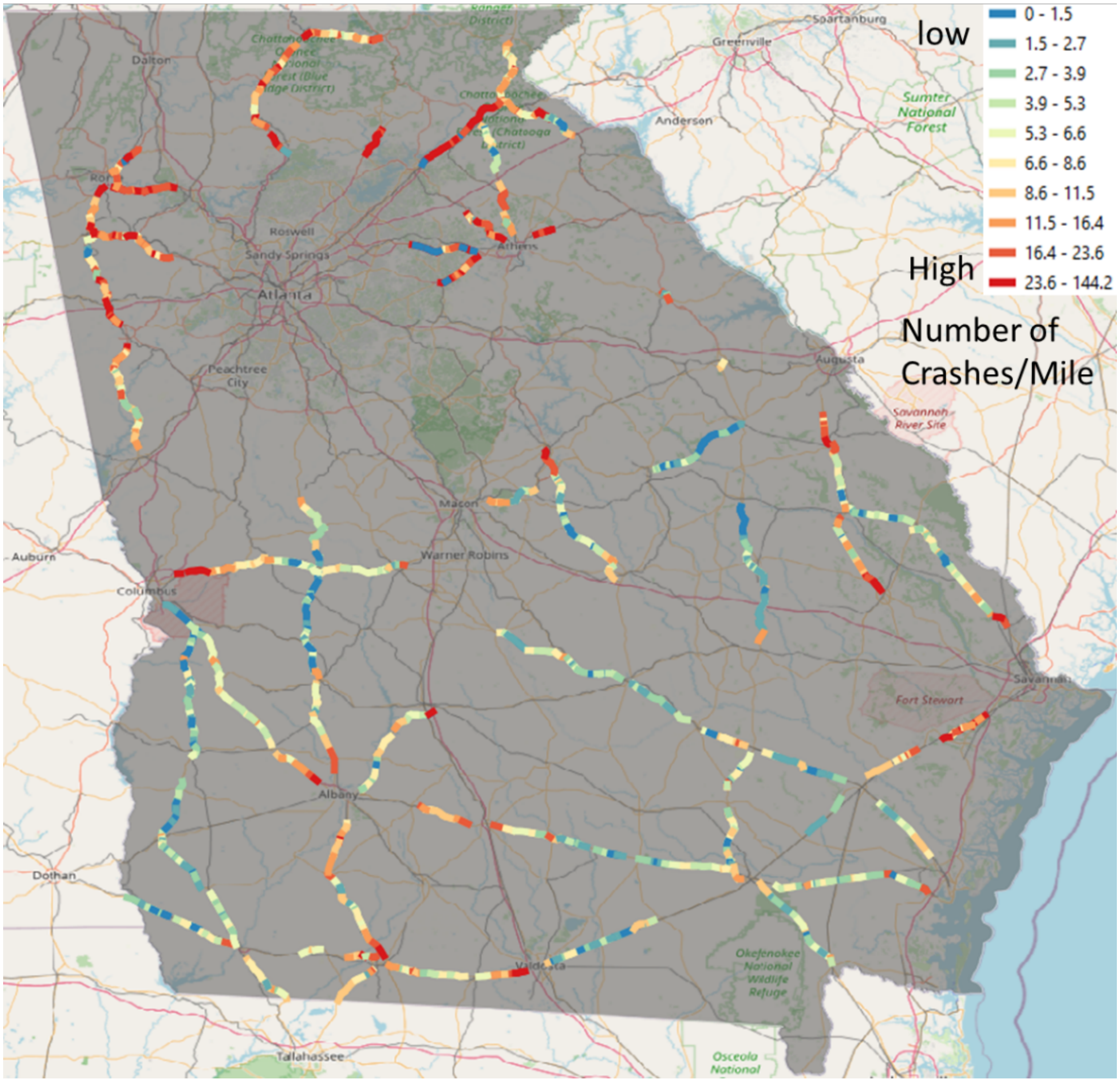


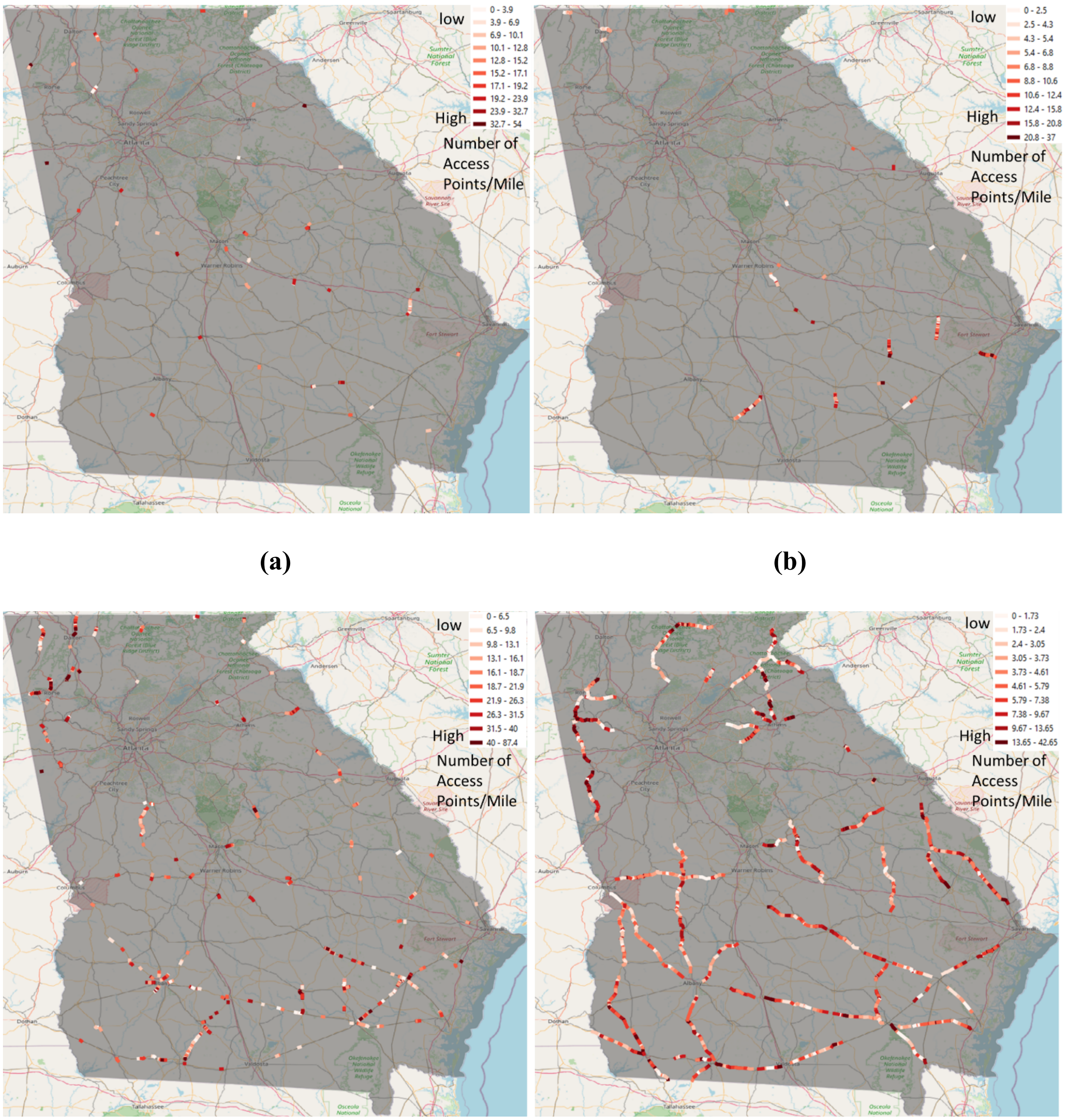
Figure 20. Number of crashes per mile along the rural four-lane non-traversable segments.

Access Points

Access point density (access points per mile) is calculated by dividing the segment length from the number of access points, Frequency distribution of access points per segment, access point density per mile, and frequency distribution of access point density are presented in Table 6. The rural four-lane TWLTL segments had the highest average access point density. In addition, this study also visualized the access point density for the sampled rural four-lane segments. No clear spatial patterns were identified for the access point density along those sampled segments.

Table 6. Number of access points and density by median type.

Number of Access Points		**UR**	**4FM**	**TWLTL**	**NTM**
0 - 5		41	111	228	661
6 - 10		16	39	162	299
11 - 30		21	15	159	207
31 - 100		1	0	9	9
Average number of Access Points per segment		7.76	4.84	8.74	6.50
APD - Access Point Density (Number of Points per Mile)	Min	0	0	0	0
	Median	15.15	8.82	18.68	4.61
	Mean	16.93	10.38	21.44	6.52
	Max	53.96	37.04	87.38	42.65
0 - 1.99		5	13	14	163
2 - 4.99		5	29	25	471
5 - 9.99		13	52	74	321
10 - 19.99		35	48	188	176
20 - 49.99		19	23	233	45
50 - 90		2	0	24	0



(a) **(b)**

(c) **(d)**

Figure 21. Number of access points per mile along the sampled rural four-lane segments (a) undivided; (b) 4-ft flush median; (c) TWLTL; (d) non-traversable.

Traffic Volume

Table 7 presents the AADT summary statistics for sampled segments from 2013 to 2018. During this period, the average traffic volumes increased about 10.9% for rural four-lane undivided segments, 16.1% for rural four-lane 4-ft flush median segments, 13.3% for rural four-lane TWLTL segments, and 19.7% for rural four-lane non-traversable segments.

Table 8 further presents the descriptive data statistics for AADT and truck percentage. The results show that the average AADT on the rural four-lane TWLTL segment was the highest (9,775) among all four median facilities. While the average truck percentage on the rural four-lane non-traversable segments was the highest (17.8) among all four median facilities.

Table 9 presents a snapshot of segment frequency and percentage by AADT and truck percentage for four facility types from 2013 to 2018. In general, the majority of the sampled rural four-lane segments had AADT less than 12,000 vehicles per day (i.e., 94%, 85%, 71%, and 79% for undivided, 4-ft flush median, TWLTL, and non-traversable segments, respectively). In other words, more TWLTL, and non-traversable segments had AADT that were 12,000 vehicles per day or greater compared to undivided and 4-ft flush median segments. Similarly, this project study found that the majority of the sampled segments had a truck percentage in the range 10 - 19.9% (i.e., 58%, 58%, 48% and 48% for undivided, 4-ft flush median, TWLTL, and non-traversable segments, respectively).

Table 7. AADT and truck percentage for 4L roads with different median types from 2013 to 2018.

UR Year	Min	Median	Mean	Max
2018 AADT (Truck %)	1,610 (5.5)	6,630 (9.9)	6,981 (10.85)	15,900 (21.4)
2017 AADT (Truck %)	870 (5.5)	6,500 (9.4)	6,707 (10.7)	15,800 (17.1)
2016 AADT (Truck %)	860 (5.6)	5,670 (13.6)	6,567 (12.79)	14,500 (24.2)
2015 AADT (Truck %)	830 (5.6)	5,580 (13.6)	6,421 (13.6)	13,900 (33.7)
2014 AADT (Truck %)	810 (5.6)	5,290 (13.7)	6,187 (14.2)	13,200 (35.4)
2013 AADT (Truck %)	1480 (5.6)	5,410 (13.2)	6,297 (12.4)	13,500 (20.9)
4FM **Year**	**Min**	**Median**	**Mean**	**Max**
2018 AADT (Truck %)	610 (3.8)	7,130 (9.2)	8,997 (11.2)	32,300 (30.3)
2017 AADT (Truck %)	460 (3.8)	6,650 (9.7)	8,754 (9.9)	32,600 (20)
2016 AADT (Truck %)	450 (2)	6,890 (11.9)	8,714 (12.33)	31,400 (25.8)
2015 AADT (Truck %)	430 (2)	6,030 (15.6)	8,231 (15.8)	31,500 (37.9)
2014 AADT (Truck %)	410 (3.3)	5,740 (15.7)	7,775 (16.8)	30,500 (39.9)
2013 AADT (Truck %)	520 (0)	6,060 (15.6)	7,748 (13.7)	30,500 (25)
TWLTL **Year**	**Min**	**Median**	**Mean**	**Max**
2018 AADT (Truck %)	1,600 (2.6)	8,935 (11.4)	10,387 (12.4)	29,100 (34)
2017 AADT (Truck %)	1,370 (2.8)	8,760 (11.9)	10,235 (12.4)	28,500 (32.6)
2016 AADT (Truck %)	1,330 (2.9)	8,460 (11.8)	10,113 (12.5)	32,500 (37.1)
2015 AADT (Truck %)	1,280 (2.4)	8,330 (11.8)	9,638 (12.9)	31,600 (43.9)
2014 AADT (Truck %)	1,220 (2.4)	7,800 (12.1)	9,106 (13.3)	28,300 (46.1)
2013 AADT (Truck %)	1,230 (2.4)	8.045 (11.8)	9,171 (12.6)	28,300 (39)
NTM **Year**	**Min**	**Median**	**Mean**	**Max**
2018 AADT (Truck %)	1,340 (2.5)	6,490 (16.6)	8,652 (17.7)	36,400 (39.5)
2017 AADT (Truck %)	1,330 (5)	6,270 (16.4)	8,416 (17)	33,800 (38.1)
2016 AADT (Truck %)	1,130 (2)	5,920 (11.1)	8,186 (18.1)	35,300 (40.3)
2015 AADT (Truck %)	1,090 (2)	5,965 (16.8)	7,802 (17.8)	34,100 (43.9)
2014 AADT (Truck %)	1,040 (4)	5,570 (16.9)	7,480 (17.9)	32,100 (46.1)
2013 AADT (Truck %)	450 (3.4)	5,450 (16.7)	7,227 (11.42)	29,100 (39)

Table 8. Average traffic volume (AADT) for different median types.

Median Type	Annual Average Daily Traffic (AADT)				
	Observations	Mean	Standard Deviation	Minimum	Maximum
UR	79	6,526	2,983	1,077	13,650
4FM	165	8,370	5,347	480	31,633
TWLTL	558	9,775	4,665	1,338	29,550
NTM	1,176	7,972	5,801	1,198	32,967
Median Type	Truck Percentage (%)				
	Observations	Mean	Standard Deviation	Minimum	Maximum
UR	79	12.9	5.2	5.6	34.4
4FM	165	13.5	5.4	2.7	25.4
TWLTL	558	12.5	6.0	2.6	38.8
NTM	1,176	17.8	7.7	4	40.0

Table 9. snapshot of segments frequency and percentage by average traffic volume (AADT) and truck percentage for different median types.

Median Type	Segments Frequency and Percentage by Traffic Volume (AADT)				
	0-5,999	6,000-11,999	12,000-17,999	18,000-23,999	24,000+
UR	49 (62%)	25 (32%)	5 (6%)	0 (0%)	0 (0%)
4FM	71 (43%)	70 (42%)	11 (7%)	9 (5%)	4 (2%)
TWLTL	122 (22%)	273 (49%)	126 (23%)	31 (6%)	6 (1%)
NTM	592 (50%)	335 (28%)	170 (14%)	48 (4%)	31 (3%)
Median Type	Segments Frequency and Percentage by Truck Percentage				
	0-4.9%	5-9.9%	10-19.9%	20-29.9%	≥ 30%
UR	0 (0%)	25 (32%)	46 (58%)	7 (9%)	1 (1%)
4FM	8 (5%)	43 (26%)	96 (58%)	18 (11%)	0 (0%)
TWLTL	29 (5%)	189 (34%)	266 (48%)	71 (13%)	3 (1%)
NTM	7 (1%)	197 (17%)	562 (48%)	344 (29%)	66 (6%)

Chapter 5: CRASH RATES

The crash rate is commonly used to evaluate the current safety ratings of the roadway facilities in practice. We adopted the measures of exposures to estimate the crash rate by vehicle miles traveled (VMT) and its equation is formulated as follows:

$$CR_{VMT} = \frac{C \times 100{,}000{,}000}{AADT \times 365 \times N \times L} \tag{7}$$

Where:

CR_{VMT} = Crash rate per 100-million VMT;

C = Total number of crashes in the 6-year study period;

$AADT$ = Average Traffic volume using Annual Average Daily Volumes (AADT) in the 6-year study period;

N = Total number of years in the study period; and

L = Length (in miles) of the roadway segment.

All Crashes

Table 10 shows that, on average, the rural four-lane non-traversable segments had a lower crash rate than segments with the other three median types. Besides that, the rural four-lane 4-ft flush median segments had the second-lowest crash rate among all median type fatalities. The average crash rate of the rural four-lane undivided roadway segment is the highest (110.85) among all four median types. Figures 22 further shows the distributions of the crash rates by 100-million VMT. The majority of sampled segments had a crash rate of 200 crashes per 100-million VMT or lower (i.e., 93%, 86%, 89%, and 97% for the rural four-lane undivided, 4-ft flush median, and non-traversable segments, respectively).

Table 10. Crash rates for undivided, 4-ft flush median, TWLTL, and non-traversable segments by 100-million VMT.

CR_{VMT} / Median Types	Observations	Mean	Standard Deviation	Minimum	Maximum
UR	79	110.85	77.62	0	332.64
4FM	165	92.69	130.76	0	1,330.48
TWLTL	558	100.46	133.53	0	1,333.75
NTM	1,176	65.62	84.71	0	1,900.19

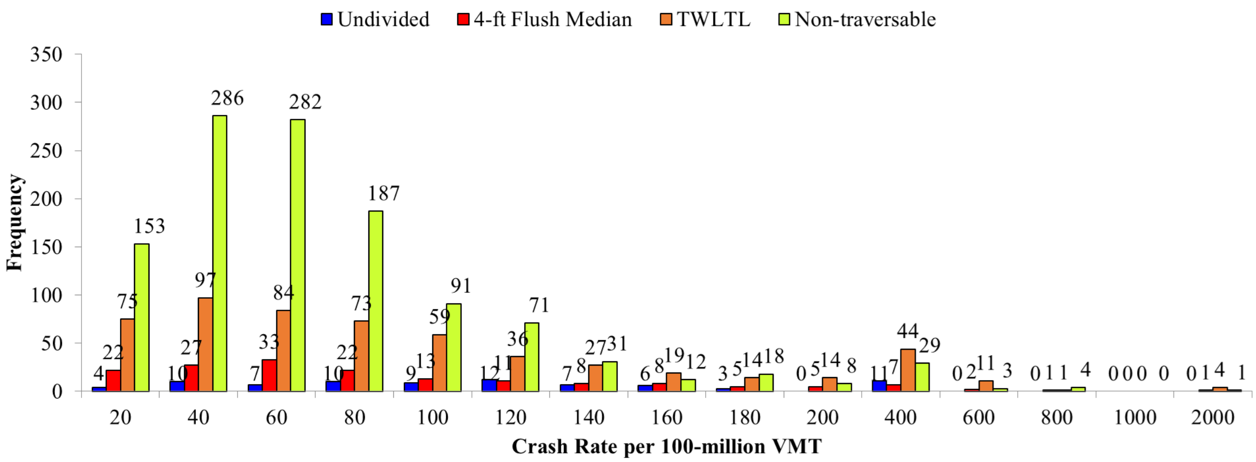


Figure 22. Distribution of the crash rates: (a) under 1000 crashes per 100-million VMT.

Crash Severity

We also estimated the crash rates for crashes of different severity levels in the KABCO scale.

- K – Fatal Injury
- A – Suspected Serious injury
- B – Suspected Minor or Visible Injury
- C – Possible Injury or Complaint
- O – No Apparent Injury

Table 11 shows that, speaking of the average fatal injury (K) and suspected serious injury (A) crash rates, rural four-lane undivided segments were associated with a significantly higher crash rate compared to the other three median types. In terms of suspected minor or visible injury (B) crash rate, the rate of rural four-lane 4FMs segments was found to have a slightly higher rate; but the rural four-lane 4FMs segments had a significantly higher rate of possible injury or complaint (C) injury crashes. In addition, the posted speed limits are further evaluated to explore the potential correlations with injury crash rates (more details can be found in Appendix A).

Table 11. Crash rates by KABCO.

CR_{VMT} / Median Types	Observations	Mean	Standard Deviation	Minimum	Maximum
K- Fatal Injury					
UR	79	3.58	12.28	0	91.85
4FM	165	0.79	2.83	0	20.19
TWLTL	558	1.65	6.73	0	66.23
UTM	1,176	1.03	3.43	0	39.78
A – Suspected Serious injury					
UR	79	19.12	26.16	0	126.84
4FM	165	15.48	20.77	0	120.85
TWLTL	558	10.91	18.91	0	128.84
UTM	1,176	9.92	15.80	0	234.59
B – Suspected Minor or Visible Injury					
UR	79	10.32	17.00	0	72.71
4FM	165	11.28	18.52	0	97.23
TWLTL	558	11.22	23.36	0	285.94
UTM	1,176	7.72	16.02	0	375.35
C – Possible Injury or Complaint					
UR	79	8.42	15.63	0	82.04
4FM	165	12.16	78.07	0	997.86
TWLTL	558	9.19	18.53	0	193.27
UTM	1,176	3.75	9.81	0	211.13
O – No Apparent Injury					
UR	79	67.17	56.90	0	277.20
4FM	165	52.17	68.71	0	471.19
TWLTL	558	65.52	97.78	0	1,176.83
UTM	1,176	42.59	55.83	0	1,079.12

Crash Type

In addition, we estimated the crash rates for a few typical crash types, using the same measure. The following crash types are used in the crash data:

- Angle
- Head-on
- Rear-end
- Sideswipe same direction
- Sideswipe opposite direction
- Other (including non-collision)

The crash rates of six crash types for four median facility types are listed in Table 12. The results show that, on average, rural four-lane TWLTL segments had a higher rate in angle, sideswipe same direction crashes; while rural four-lane undivided segments had a higher rate in head-on, sideswipe opposite direction, and others (including non-collision) crashes; and rural four-lane 4-ft flush median segments had a higher rate of rear-end crashes.

Table 12. Crash rates by crash type.

CR_{VMT} / Median Types	Observations	Mean	Standard Deviation	Minimum	Maximum
Angle					
UR	79	23.73	35.60	0	149.77
4FM	165	2.11	2.19	0	48.19
TWLTL	558	25.41	51.28	0	601.49
UTM	1,176	9.36	17.03		234.59
Head-on					
UR	79	3.54	12.26	0	91.85
4FM	165	2.12	6.19	0	48.19
TWLTL	558	2.28	8.63	0	103.77
UTM	1,176	1.08	3.74	0	70.38
Rear-end					
UR	79	22.99	32.31	0	158.54
4FM	165	38.15	113.59	0	1,330.48
TWLTL	558	25.13	51.42	0	601.49
UTM	1,176	12.77	37.04	0	844.53
Sideswipe same direction					
UR	79	5.28	9.62	0	30.06
4FM	165	7.07	12.66	0	68.79
TWLTL	558	9.72	20.69	0	214.62
UTM	1,176	4.99	11.22	0	211.13
Sideswipe opposite direction					
UR	79	1.84	6.05	0	30.36
4FM	165	0.67	3.54	0	29.92
TWLTL	558	1.35	4.79	0	41.61
UTM	1,176	0.48	2.63	0	46.63
Others (including non-collision)					
UR	79	49.73	50.23	0	246.18
4FM	165	29.63	31.44	0	181.72
TWLTL	558	34.37	44.03	0	450.96
UTM	1,176	36.07	38.79	0	469.18

Single- and Multi-vehicle Crashes

We also estimated the crash rates for single- and multi-vehicle crash rates. As shown in Table 13 across the first three median types of segments (i.e., UR, 4FM, TWLTL), the average crash rates for multi-vehicle crashes were greater than rates for single-vehicle crashes. However, the single-vehicle crash rate on the non-traversable segments was higher than the rate for multi-vehicle crashes.

Table 13. Crash rates for single- and multi-vehicle crashes.

CR_{VMT} / Median Types	Observations	Mean	Standard Deviation	Minimum	Maximum
Single-vehicle crash					
UR	79	54.46	53.25	0	246.18
4FM	165	32.46	33.31	0	201.92
TWLTL	558	35.69	43.98	0	450.96
UTM	1,176	37.61	40.24	0	539.56
Multi-vehicle crash					
UR	79	56.39	52.77	0	221.96
4FM	165	60.23	123.00	0	1,330.48
TWLTL	558	64.77	112.04	0	1,225.29
UTM	1,176	28.00	58.73	0	1,360.63

Chapter 6: SAFETY PERFORMANCE FUNCTIONS

This section summarizes the SPFs that were developed for the following four segment types on rural 4L roads: UR, TWLTL, 4FM, NTM.

The SPFs were developed by the team using the manipulated data. Both traditional Negative Binomial (NB) models and the random-parameter (RP) NB models were estimated. The RP-NB models are able to account for the unobserved heterogeneity due to the limited number of variables in the modeling. The RP models appear to outperform the traditional NB models, according to Akaike's Information Criterion, as shown in Table 14. Therefore, the SPFs estimated from RP-NB models are used for crash frequency prediction, finally to calculate CMFs.

In general, these parameters look reasonable. The traffic volumes (AADT) and segment length, as the exposure variables, are positively related to crash frequencies. The factor of access point density is positively related to the crash numbers, because of more access points, more potential conflicts between vehicles on a segment.

Table 14. SPFs by crash severity.

SPF Parameters	a Constant	b Ln (AADT)	c Seg. length	d Truck Pct.	e APD	f Interaction	N	AIC
All Crashes (KABCO)								
UR	-10.689***	1.286***	0.886***	0.243	0.009	-0.027	79	202
4FM	-16.338***	1.887***	0.720***	0.105	0.015	-0.013	165	456
TWLTL	-8.527***	1.049***	0.883***	0.064	0.017***	-0.012	558	1,515
NTM	-5.229***	0.706***	0.946***	0.015	0.012***	-0.006***	1,176	3,668
Injury Crashes (KAB)								
UR	-12.479*	1.377*	1.288***	0.255	0.006	-0.029	79	112
4FM	-14.692**	1.557**	0.633***	0024	0.010	-0.002	165	234
TWLTL	-10.820***	1.113***	0.914***	0.211	0.021***	-0.026	558	658
NTM	-5.107***	0.539***	1.004***	-0.04	0.013*	0.001	1,176	1,815
No Injury Crashes (O)								
UR	-11.658	1.256	0.934***	0.150	0.002	-0.014	79	111
4FM	-21.560***	2.397***	0.869***	0.099	0.028*	-0.012	165	317
TWLTL	-8.794***	1.050***	0.916***	-0.005	0.014***	-0.005	558	1,245
NTM	-6.268***	0.784***	0.938***	0.033	0.011**	-0.009	1,176	3,027
Possible Injury or No Injury Crashes (CO)								
UR	-11.227**	1.318***	0.866***	0.294	0.010	-0.034	79	170
4FM	-17.622***	1.994***	0.812***	-0.148	0.024*	0.014	165	343
TWLTL	-8.856***	1.076***	0.922***	-0.031	0.015***	-0.002	558	1332
NTM	-6.227***	0.791***	0.935***	0.022	0.009*	-0.007	1,176	3074
Fatal Injury Crashes (K)								
UR	-7.390	0.400	1.029**	-0.136	0.031	0.021	79	33
4FM	-28.176**	2.829**	1.313***	1.186	-0.042	-0.136	165	38
TWLTL	-4.658	0.111	0.792***	-0.318	0.022**	0.034	558	115
NTM	-3.138	-0.039	0.970***	-0.357**	0.003	0.040**	1,176	301

Notes: "*", "**", and "***" indicate significance at 10%, 5%, and 1% level, respectively, N = number of observations; AIC = Akaike's Information Criterion. "-" indicates not available. SPFs for fatal crashes are estimated, however, it is not recommended to apply these SPFs due to unreliable model estimates with insufficient data.

Chapter 7: CRASH MODIFICATION FACTORS

The CMFs are calculated to show the effectiveness of a cross-section compared to the base cross-section which is a 4L-UR. CMFs are likely to vary across different values of AADT, segment length, truck percent, and access point density, indicating that the safety effectiveness of a treatment on roadways is likely to vary across different situations. This study predicted the crash frequencies for one mile of segments. CMFs are estimated by keeping one of the factors (AADT, truck percent, access point density) constant and varying the other two factors. CMFs were calculated for typical values of AADT, truck percentage, and access point density. Tables 15 to 19 show the results for different access point densities. According to these tables, the overall key findings are as follows:

- The segments with NTMs outperform the other three segment types across all AADTs, truck percentages and access point densities, except the very low AADT around 3,000 where the 4FMs appear to be associated with an improved condition. When traffic volumes are low, the NTMs may create a "too perfect" free-flow condition for the traffic, and speeding-related crashes are frequent on low-volume rural 4L roadways.
- AADT – Is a principal factor to show the effectiveness of a cross-section compared to the base. In general, the 4FMs appear to have an improved performance than UR segments when the AADT is low (around or lower than 9,000); when the AADT increases (around or higher than 9,000), the TWLTLs have an improved performance than UR section and 4FMs; when the AADT reaches 20,000, the NTMs may be considered.
- Truck percentage – Is positively related to the safety effectiveness of 4FM (when AADT < 12,000), TWLTLs and NTMs compared to the base segment type. In other words,

converting a 4L-UR segment into one of the other three cross-section types can result in an even further improved condition for traffic with a higher truck percentage.

- Access point density – Is negatively related to the safety effectiveness of 4FMs, TWLTLs and NTMs compared to the base segment type. In other words, the safety effectiveness of these three types of medians decreases with the increase in the number of access points along a segment.

Besides the CMF tables, Appendix B presented more details regarding the trends of CMFs along with the AADT, for different truck percentages and access point densities. The CMF plots are developed for crash severity groups including KABCO, KAB and CO crashes.

Table 15. CMFs based on AADT with UR segments as base (Access point density - 10 per mile).

AADT \ Truck %	5%	10%	15%	20%	25%
UR					
3000	1	1	1	1	1
6000	1	1	1	1	1
9000	1	1	1	1	1
12000	1	1	1	1	1
15000	1	1	1	1	1
18000	1	1	1	1	1
21000	1	1	1	1	1
24000	1	1	1	1	1
4FM					
3000	0.407	0.360	0.318	0.282	0.249
6000	0.648	0.602	0.559	0.520	0.483
9000	0.850	0.813	0.778	0.744	0.712
12000	1.032	1.007	0.983	0.960	0.937
15000	1.198	1.188	1.179	1.169	1.159
18000	1.354	1.361	1.367	1.373	1.380
21000	1.502	1.526	1.550	1.574	1.599
24000	1.643	1.685	1.727	1.771	1.816
TWLTL					
3000	1.051	0.792	0.597	0.450	0.339
6000	0.940	0.747	0.594	0.472	0.375
9000	0.881	0.722	0.592	0.486	0.398
12000	0.841	0.705	0.591	0.496	0.416
15000	0.811	0.692	0.590	0.503	0.429
18000	0.788	0.682	0.590	0.510	0.441
21000	0.769	0.673	0.589	0.515	0.451
24000	0.752	0.665	0.588	0.520	0.460
NTM					
3000	1.713	1.266	0.936	0.692	0.511
6000	1.232	0.979	0.778	0.618	0.491
9000	1.015	0.842	0.698	0.579	0.480
12000	0.885	0.756	0.646	0.552	0.472
15000	0.796	0.696	0.609	0.533	0.466
18000	0.730	0.651	0.580	0.517	0.461
21000	0.678	0.614	0.557	0.504	0.457
24000	0.637	0.585	0.537	0.493	0.453

Table 16. CMFs based on AADT with UR segments as base (Access point density - 20 per mile).

AADT \ Truck %	5%	10%	15%	20%	25%
Undivided					
3000	1	1	1	1	1
6000	1	1	1	1	1
9000	1	1	1	1	1
12000	1	1	1	1	1
15000	1	1	1	1	1
18000	1	1	1	1	1
21000	1	1	1	1	1
24000	1	1	1	1	1
4FM					
3000	0.433	0.383	0.339	0.300	0.265
6000	0.689	0.640	0.595	0.553	0.514
9000	0.905	0.865	0.828	0.792	0.757
12000	1.098	1.072	1.046	1.021	0.997
15000	1.275	1.265	1.254	1.244	1.234
18000	1.441	1.448	1.455	1.461	1.468
21000	1.599	1.624	1.649	1.675	1.701
24000	1.749	1.793	1.838	1.885	1.933
TWLTL					
3000	1.132	0.853	0.643	0.484	0.365
6000	1.012	0.805	0.640	0.508	0.404
9000	0.948	0.778	0.638	0.523	0.429
12000	0.906	0.759	0.637	0.534	0.447
15000	0.874	0.745	0.636	0.542	0.462
18000	0.848	0.734	0.635	0.549	0.475
21000	0.828	0.724	0.634	0.555	0.486
24000	0.810	0.716	0.634	0.560	0.495
NTM					
3000	1.764	1.304	0.964	0.712	0.526
6000	1.269	1.008	0.801	0.637	0.506
9000	1.046	0.867	0.719	0.596	0.494
12000	0.912	0.779	0.666	0.569	0.486
15000	0.820	0.717	0.627	0.549	0.480
18000	0.752	0.670	0.597	0.533	0.475
21000	0.699	0.633	0.573	0.519	0.471
24000	0.656	0.602	0.553	0.508	0.467

Table 17. CMFs based on AADT with UR segments as base (Access point density - 30 per mile).

AADT \ Truck %	5%	10%	15%	20%	25%
UR					
3000	1	1	1	1	1
6000	1	1	1	1	1
9000	1	1	1	1	1
12000	1	1	1	1	1
15000	1	1	1	1	1
18000	1	1	1	1	1
21000	1	1	1	1	1
24000	1	1	1	1	1
4FM					
3000	0.460	0.407	0.360	0.319	0.282
6000	0.733	0.682	0.633	0.589	0.547
9000	0.963	0.921	0.881	0.842	0.806
12000	1.168	1.140	1.113	1.087	1.061
15000	1.357	1.346	1.335	1.324	1.313
18000	1.534	1.541	1.548	1.555	1.562
21000	1.701	1.728	1.755	1.782	1.810
24000	1.861	1.908	1.956	2.006	2.056
TWLTL					
3000	1.219	0.918	0.692	0.522	0.393
6000	1.090	0.866	0.689	0.547	0.435
9000	1.021	0.838	0.687	0.563	0.462
12000	0.975	0.818	0.685	0.575	0.482
15000	0.941	0.802	0.684	0.584	0.498
18000	0.914	0.790	0.684	0.591	0.511
21000	0.891	0.780	0.683	0.598	0.523
24000	0.872	0.771	0.682	0.603	0.534
NTM					
3000	1.817	1.343	0.993	0.734	0.542
6000	1.307	1.038	0.825	0.656	0.521
9000	1.077	0.893	0.740	0.614	0.509
12000	0.939	0.803	0.686	0.586	0.501
15000	0.845	0.739	0.646	0.565	0.494
18000	0.774	0.690	0.615	0.549	0.489
21000	0.720	0.652	0.591	0.535	0.485
24000	0.675	0.620	0.570	0.524	0.481

Table 18. CMFs based on AADT with UR segments as base (Access point density - 40 per mile).

Truck % / AADT	5%	10%	15%	20%	25%
UR					
3000	1	1	1	1	1
6000	1	1	1	1	1
9000	1	1	1	1	1
12000	1	1	1	1	1
15000	1	1	1	1	1
18000	1	1	1	1	1
21000	1	1	1	1	1
24000	1	1	1	1	1
4FM					
3000	0.490	0.433	0.384	0.339	0.300
6000	0.780	0.725	0.674	0.626	0.582
9000	1.025	0.980	0.937	0.897	0.857
12000	1.243	1.213	1.184	1.156	1.129
15000	1.444	1.432	1.420	1.408	1.397
18000	1.632	1.640	1.647	1.655	1.663
21000	1.810	1.839	1.867	1.897	1.926
24000	1.980	2.030	2.082	2.134	2.188
TWLTL					
3000	1.312	0.989	0.745	0.562	0.423
6000	1.174	0.933	0.742	0.590	0.469
9000	1.100	0.902	0.740	0.606	0.497
12000	1.050	0.880	0.738	0.619	0.519
15000	1.013	0.864	0.737	0.629	0.536
18000	0.984	0.851	0.736	0.637	0.551
21000	0.960	0.840	0.735	0.644	0.563
24000	0.939	0.831	0.735	0.650	0.574
NTM					
3000	1.872	1.383	1.022	0.756	0.558
6000	1.346	1.069	0.850	0.675	0.537
9000	1.110	0.920	0.763	0.632	0.524
12000	0.968	0.827	0.706	0.603	0.516
15000	0.870	0.761	0.665	0.582	0.509
18000	0.798	0.711	0.634	0.565	0.504
21000	0.741	0.672	0.608	0.551	0.499
24000	0.696	0.639	0.587	0.539	0.495

Table 19. CMFs based on AADT with UR segments as base (Access point density - 50 per mile).

AADT \ Truck %	5%	10%	15%	20%	25%
UR					
3000	1	1	1	1	1
6000	1	1	1	1	1
9000	1	1	1	1	1
12000	1	1	1	1	1
15000	1	1	1	1	1
18000	1	1	1	1	1
21000	1	1	1	1	1
24000	1	1	1	1	1
4FM					
3000	0.521	0.461	0.408	0.361	0.319
6000	0.830	0.772	0.717	0.667	0.619
9000	1.090	1.043	0.997	0.954	0.912
12000	1.323	1.291	1.260	1.230	1.201
15000	1.537	1.524	1.511	1.499	1.486
18000	1.737	1.745	1.753	1.761	1.769
21000	1.926	1.956	1.987	2.018	2.050
24000	2.107	2.160	2.215	2.271	2.329
TWLTL					
3000	1.413	1.065	0.802	0.605	0.456
6000	1.264	1.005	0.799	0.635	0.505
9000	1.184	0.971	0.796	0.653	0.536
12000	1.131	0.948	0.795	0.666	0.559
15000	1.091	0.930	0.794	0.677	0.577
18000	1.059	0.916	0.793	0.686	0.593
21000	1.033	0.904	0.792	0.693	0.607
24000	1.011	0.894	0.791	0.699	0.619
NTM					
3000	1.928	1.425	1.053	0.778	0.575
6000	1.386	1.102	0.875	0.696	0.553
9000	1.143	0.948	0.786	0.651	0.540
12000	0.997	0.851	0.728	0.622	0.531
15000	0.896	0.784	0.685	0.599	0.524
18000	0.822	0.732	0.653	0.582	0.519
21000	0.764	0.692	0.627	0.568	0.514
24000	0.716	0.658	0.605	0.555	0.510

Chapter 8: CRITERIA DEVELOPMENT

When selecting a median type for GRIP roadways, recognition of average annual daily traffic, truck needs, and property access demands are to be considered. On certain projects, more than one cross-section may be necessary or desirable, and consideration of these needs should be made along the corridor to confirm the suitable cross-section choice. The length of the project will influence the selection of the cross-section. Short highway sections should limit the number of cross-section changes; whereas, longer highway sections may consist of many cross-section changes. Changes in cross-sections should be limited to logical transition points, such as natural boundaries or political boundaries.

The criteria are intended to be given for ranges of road or traffic conditions, i.e., AADT, truck percentage, and access point density, as shown in Table 20. However, within each cell, there can be thousands of combinations of these three factors. Tables 15 and 19 only showed a few CMFs, for example conditions. 1,000 possible conditions were randomly generated within each cell in Table 20 and estimated the CMFs to show the effectiveness of three cross-sections compared to the base cross-section – UR under these 1,000 random conditions. Table 20 shows the average CMFs within each cell, showing the average effectiveness of improving safety performance by converting an undivided road to a target cross-section. The CMFs greater than 1.00 are not shown in the Table. For AADTs under 5,000 (regardless of the access point density and truck percentage), the average CMFs range from 0.2 to 0.42. It means that converting an UR to a cross-section with 4FMs could reduce the crash numbers by 58% to 80%. For AADTs between 5000 to 10,000, the crash numbers could be reduced by 11% to 43%. From Table 20, in general, the 4FMs seem to be effective in improving safety performance when AADTs are under 10,000, and they are more effective for traffic with higher truck percentages. When AADTs are above 10,000, TWLTLs and NTMs have comparable CMFs.

Table 20. Average CMFs for given road/traffic conditions (KABCO crashes).

	Truck Percentage	Vehicle AADT																							
		<=5,000				>5,000 to 10,000				>10,000 to 15,000				>15,000 to 20,000				>20,000 to 25,000				>25,000			
		Access Point Density, AP/mile																							
		<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30
4-ft Flush Median	<=5%	0.36	0.39	0.40	0.42	0.75	0.79	0.84	0.89	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>5% to <=10%	0.31	0.33	0.35	0.37	0.70	0.74	0.78	0.84	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>10% to <=15%	0.26	0.30	0.31	0.33	0.65	0.69	0.74	0.79	0.98	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>15% to <=20%	0.24	0.25	0.27	0.29	0.62	0.65	0.69	0.74	0.95	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>20%	0.20	0.22	0.24	0.25	0.57	0.61	0.65	0.69	0.92	0.98	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TWLTL	<=5%	N/A	N/A	N/A	N/A	0.98	N/A	N/A	N/A	0.88	0.95	N/A	N/A	0.83	0.90	0.97	N/A	0.78	0.85	0.92	1.00	0.76	0.82	0.88	0.96
	>5% to <=10%	0.94	N/A	N/A	N/A	0.78	0.85	0.92	0.99	0.73	0.79	0.86	0.93	0.70	0.76	0.82	0.89	0.68	0.74	0.80	0.86	0.66	0.72	0.78	0.84
	>10% to <=15%	0.67	0.72	0.78	0.85	0.62	0.67	0.73	0.79	0.61	0.66	0.71	0.77	0.60	0.65	0.70	0.76	0.59	0.64	0.69	0.75	0.58	0.63	0.68	0.74
	>15% to <=20%	0.48	0.52	0.56	0.61	0.50	0.54	0.58	0.63	0.50	0.54	0.59	0.64	0.51	0.55	0.59	0.64	0.51	0.55	0.60	0.65	0.51	0.56	0.60	0.65
	>20%	0.35	0.37	0.41	0.44	0.40	0.43	0.46	0.50	0.42	0.45	0.49	0.53	0.43	0.47	0.51	0.55	0.44	0.48	0.52	0.56	0.45	0.49	0.53	0.57
Non-traversable	<=5%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.94	0.96	0.99	N/A	0.78	0.81	0.83	0.86	0.68	0.71	0.73	0.75	0.62	0.63	0.65	0.67
	>5% to <=10%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.81	0.83	0.85	0.88	0.70	0.72	0.74	0.76	0.63	0.65	0.66	0.69	0.58	0.59	0.61	0.63
	>10% to <=15%	N/A	N/A	N/A	N/A	0.82	0.85	0.87	0.89	0.69	0.72	0.74	0.76	0.62	0.64	0.66	0.68	0.57	0.59	0.61	0.63	0.54	0.55	0.57	0.59
	>15% to <=20%	0.92	0.95	0.98	N/A	0.67	0.69	0.71	0.73	0.59	0.62	0.63	0.65	0.56	0.57	0.59	0.61	0.53	0.54	0.56	0.57	0.50	0.52	0.53	0.55
	>20%	0.64	0.66	0.68	0.70	0.54	0.56	0.58	0.59	0.51	0.53	0.54	0.56	0.49	0.51	0.53	0.54	0.48	0.50	0.51	0.53	0.47	0.49	0.50	0.52

Notes: The CMF calculation base cross-section is undivided roadways. Cells with "N/A" are estimated with average CMFs greater than 1.00. The results are applicable to roadways with posted speed limits of 50 mph and higher. These CMFs shown in this table are for all crashes (KABCO). Appendix C provides estimated CMFs for KAB, and CO crashes.

The CMFs are calculated by comparing predicted crash numbers between two types of cross-sections. The base crash numbers matter for the magnitudes of CMFs. The CMFs can be used to indicate the percent reduction in crash numbers. CMFs are useful when applying different countermeasures under the same road or traffic conditions. When it comes to recommending countermeasures for different conditions, it may be more reasonable to compare the concrete crash reduction numbers. Table 21 shows the average reduced annual crash frequencies if converting a UR to a cross-section with 4FMs, TWLTLs, and NTMs, respectively.

Table 21. Average crash reduction per year for given road/traffic conditions.

	Truck Percentage	Vehicle AADT																							
		<=5,000				>5,000 to 10,000				>10,000 to 15,000				>15,000 to 20,000				>20,000 to 25,000				>25,000			
		Access Point Density, AP/mile																							
		<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30
4-ft Flush Median	<=5%	-0.35	-0.36	-0.38	-0.39	-0.54	-0.48	-0.38	-0.25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>5% to <=10%	-0.44	-0.45	-0.48	-0.5	-0.66	-0.6	-0.52	-0.43	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>10% to <=15%	-0.54	-0.56	-0.61	-0.64	-0.77	-0.73	-0.69	-0.59	-0.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>15% to <=20%	-0.66	-0.71	-0.75	-0.79	-0.87	-0.86	-0.83	-0.77	-0.16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>20%	-0.82	-0.84	-0.93	-0.98	-0.98	-0.98	-0.96	-0.91	-0.25	-0.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TWLTL	<=5%	N/A	N/A	N/A	N/A	-0.06	N/A	N/A	N/A	-0.52	-0.22	N/A	N/A	-1.13	-0.74	-0.25	N/A	-1.89	-1.41	-0.82	-0.02	-2.77	-2.27	-1.54	-0.59
	>5% to <=10%	-0.10	-0.04	N/A	N/A	-0.52	-0.41	-0.25	-0.04	-1.1	-0.92	-0.69	-0.37	-1.74	-1.53	-1.23	-0.82	-2.46	-2.21	-1.87	-1.36	-3.20	-2.94	-2.55	-1.94
	>10% to <=15%	-0.29	-0.26	-0.23	-0.19	-0.89	-0.84	-0.75	-0.65	-1.5	-1.43	-1.31	-1.14	-2.12	-2.03	-1.89	-1.67	-2.74	-2.65	-2.47	-2.21	-3.36	-3.25	-3.04	-2.73
	>15% to <=20%	-0.49	-0.50	-0.49	-0.47	-1.20	-1.20	-1.19	-1.14	-1.79	-1.8	-1.77	-1.7	-2.33	-2.34	-2.3	-2.21	-2.85	-2.85	-2.79	-2.68	-3.33	-3.33	-3.27	-3.11
	>20%	-0.71	-0.70	-0.76	-0.77	-1.44	-1.50	-1.19	-1.57	-1.98	-2.04	-2.08	-2.09	-2.43	-2.49	-2.52	-2.53	-2.83	-2.88	-2.92	-2.91	-3.19	-3.25	-3.27	-3.24
Non-traversable	<=5%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	-0.32	-0.20	-0.07	N/A	-1.42	-1.39	-1.35	-1.25	-2.78	-2.83	-2.90	-2.90	-4.32	-4.54	-4.69	-4.80
	>5% to <=10%	N/A	N/A	N/A	N/A	-0.02	N/A	N/A	N/A	-0.82	-0.76	-0.72	-0.65	-1.77	-1.80	-1.83	-1.83	-2.88	-2.98	-3.10	-3.13	-4.03	-4.26	-4.45	-4.61
	>10% to <=15%	N/A	N/A	N/A	N/A	-0.44	-0.43	-0.38	-0.35	-1.18	-1.21	-1.21	-1.21	-2.00	-2.07	-2.15	-2.22	-2.85	-2.99	-3.13	-3.27	-3.73	-3.94	-4.14	-4.36
	>15% to <=20%	-0.17	-0.17	-0.15	-0.12	-0.81	-0.82	-0.85	-0.85	-1.45	-1.53	-1.59	-1.65	-2.11	-2.23	-2.33	-2.44	-2.76	-2.92	-3.07	-3.25	-3.40	-3.61	-3.82	-4.02
	>20%	-0.44	-0.43	-0.47	-0.48	-1.10	-1.16	-1.23	-1.29	-1.65	-1.76	-1.85	-1.95	-2.15	-2.29	-2.42	-2.57	-2.63	-2.79	-2.97	-3.15	-3.07	-3.27	-3.48	-3.70

Notes: The base cross-section is undivided roadways. Cells with "N/A" are estimated with no crash reduction from the base cross-section. The results are applicable to roadways with posted speed limits of 50 mph and higher. The results are for all crashes (KABCO).

Further, project decisions are often made based on the benefits and costs of alternative designs or countermeasures. In this project, the crash reductions could be translated as the safety benefits of a highway project or a countermeasure on a roadway. Crashes have different severities, which associate with uneven safety benefits. Table 22 shows the benefits of reductions for crashes of different severities (GDOT, 2019a).

Table 22. Safety benefits for different crash severities (GDOT, 2019a).

Crash Severity	$ Benefit
K	$ 10,450,271.99
A	$ 2,285,054.32
B	$ 500,966.66
C	$ 109,889.46
O	$ 23,701.65

To consider the crash severity in the safety benefit estimation, we estimated the crash reductions for different severities using the crash severity distributions and the total crash reductions. As shown in Table 23, URs are associated with the greatest percentages of fatal and suspected severe crashes (KA) among all crashes on undivided roadways. Within the other three types of cross-sections, segments with non-traversable medians are linked with greater shares of fatal and severe crashes.

Table 23. Crash severity distributions on four cross-section types.

Cross-section Type	K	A	B	C	O
Undivided	2.48%	17.72%	10.93%	8.11%	60.76%
4-ft Flush Median	1.20%	13.96%	12.50%	7.78%	64.56%
TWLTL	1.36%	10.53%	10.55%	9.62%	67.94%
Non-traversable	1.48%	14.51%	11.68%	6.40%	65.93%

Though the speed limits across four types of cross-sections are 50 mph or higher (i.e., 55 mph, 65 mph) in this project, the travel speeds of vehicles on roadways with NTMs may be higher than those on the other three types of roadways. Higher speeds are associated with severer crashes. The information on vehicle speeds prior to crashes is currently not available to the project team, but it would be worthwhile to investigate the relationships between the vehicle travel speeds and the median types under the same speed limits.

With the predicted crash reductions for different severities and the severity-based safety benefits per crash, the authors estimated the safety benefits for 4FMs, TWLTLs, and NTMs compared with URs as the base. The safety benefits are estimated for the 20 years and all safety benefits are converted to Net Present Values (NPVs).

$$NPV\ of\ Total\ Benefits = \sum_{t=1}^{20} \frac{Base\ Benefits * (1 + Inflation\ Rate)^t * (1 + Income\ Rate)^t}{(1 + Discount\ Rate)^t}$$

(8)

where the Base Benefits are the estimated safety benefits from the crash reductions in the current year; t is the number of years. The inflation rate used in this project is 2% (U.S. BLS SIO, 2019), the income discount rate is 2.5% (DON, 2018), and the discount rate is 4% (GDOT, 2019b).

Table 24 shows the estimated safety benefits in net present values for 4FMs, TWLTLs, and NTMs compared with URs as the base. The numbers shown in Table 24 are the reduced crash costs in 20 years. Note that, positive values, i.e., negative safety benefits, are not shown in the table. Besides, the safety benefits estimated in this project do not consider the changes in traffic volumes and road environments (i.e., access points) in the future.

Table 24. Safety Benefits (in $million) for 4FMs, TWLTLs, and NTMs compared with URs.

	Truck Percentage	Vehicle AADT																							
		<=5,000				>5,000 to 10,000				>10,000 to 15,000				>15,000 to 20,000				>20,000 to 25,000				>25,000			
		Access Point Density, AP/mile																							
		<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30
4-ft Flush Median	<=5%	$7	$7	$8	$6	$16	$17	$17	$16	$17	$15	$13	$18	$8	$2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>5% to <=10%	$8	$9	$9	$8	$18	$18	$18	$17	$17	$16	$14	$18	$8	$3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>10% to <=15%	$10	$10	$11	$9	$19	$20	$20	$18	$18	$16	$15	$18	$7	$3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>15% to <=20%	$12	$12	$13	$11	$20	$21	$22	$20	$18	$17	$15	$18	$7	$3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>20%	$14	$15	$16	$13	$22	$23	$24	$21	$18	$17	$16	$18	$7	$3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TWLTL	<=5%	$3	$2	$2	$3	$14	$14	$13	$15	$30	$30	$29	$30	$49	$49	$48	$49	$71	$71	$70	$69	$93	$95	$95	$91
	>5% to <=10%	$5	$5	$5	$5	$19	$19	$19	$18	$35	$35	$35	$34	$51	$53	$53	$50	$69	$71	$72	$67	$87	$90	$92	$84
	>10% to <=15%	$8	$8	$8	$7	$23	$23	$24	$22	$37	$39	$40	$36	$52	$54	$56	$49	$66	$69	$71	$63	$80	$84	$87	$77
	>15% to <=20%	$10	$11	$11	$10	$26	$27	$28	$24	$39	$41	$43	$37	$51	$53	$56	$48	$62	$65	$68	$59	$73	$77	$80	$69
	>20%	$13	$14	$15	$12	$28	$30	$32	$26	$39	$42	$44	$37	$49	$52	$55	$46	$57	$61	$64	$54	$65	$69	$73	$61
Non-traversable	<=5%	N/A	N/A	N/A	N/A	$3	$2	$1	$3	$19	$20	$20	$19	$41	$43	$44	$39	$66	$70	$73	$62	$93	$99	$106	$87
	>5% to <=10%	N/A	N/A	N/A	N/A	$9	$9	$9	$9	$25	$26	$26	$23	$43	$45	$48	$40	$62	$66	$71	$59	$83	$89	$95	$78
	>10% to <=15%	$2	$2	$2	$2	$14	$15	$15	$13	$28	$30	$31	$27	$43	$46	$49	$40	$59	$63	$67	$55	$74	$80	$85	$69
	>15% to <=20%	$6	$6	$6	$5	$18	$19	$20	$17	$31	$33	$35	$29	$43	$46	$49	$40	$54	$58	$62	$51	$66	$71	$76	$61
	>20%	$9	$10	$10	$9	$22	$24	$25	$20	$32	$35	$37	$30	$42	$45	$48	$39	$50	$54	$58	$47	$58	$62	$67	$54

Notes: The base cross-section type is undivided roadways. The safety benefits cover reductions in all crash types. The safety benefits of 20 years are estimated. Cells with "N/A" are estimated with negative safety benefits. The results are applicable to roadways with posted speed limits of 50 mph and higher.

In addition to the benefits that a proposed project or countermeasure can bring, the cost of a project is also a major factor that decision-makers consider. The cost often includes construction cost and all ancillary costs such as right-of-way, utilities, etc. A benefit-cost ratio (BCR) is often used as an indicator to show the relationship between the relative costs and benefits of a proposed project, expressed in monetary or qualitative terms. If a project has a BCR greater than 1.0, the project is expected to deliver a positive net present value to the investment. An alternative project or countermeasure with a greater BCR is often preferred and selected for construction or implementation.

With the assistance of GDOT, the research team obtained the cost data for several recent projects related to the median types of interest in this research project. The data include the project costs for expanding two-lane roadways to 4L roadways of different cross-sections (e.g., 4FMs, TWLTLs, and NTMs) in rural areas. In addition, from other states, we obtained the project cost data for expanding two-lane roadways to 4L undivided roadways (Capitol Fax.com, 2010; Hillsborough MPO, 2014; FDOT, 2019a; FDOT, 2019b). All these cost data allowed to roughly compare the cost differences between UR and 4FMs, TWLTLs, and NTMs.

Table 25. The per-mile cost differences for roadways with 4FMs, TWLTLs, and NTMs are compared with URs.

	Additional Cost (million $) from undivided roadways, per mile	
Cross-section Type	Lower Bound	Upper Bound
4-ft Flush Median	$0.48M	$2.65M
TWLTL	$2.73M	$3.98M
Non-traversable	$1.21M	$6.85M

Using the upper bound cost differences (to be conservative) and assuming there is a proposed project to convert four-lane undivided roadways to 4FM, TWLTLs, or NTMs, the authors calculated the BCRs for three types of cross-sections, as shown in Table 26. The results show that, though the roadways with non-traversable medians are seen a great number of crash reductions (Table 21), the BCRs for such cross-sections are not equally promising due to the cost of constructing them (especially compared with the TWLTLs).

Table 26. BCRs for 4FMs, TWLTLs, and NTMs (the base cross-section is UR).

	Truck Percentage	Vehicle AADT																							
		<=5,000				>5,000 to 10,000				>10,000 to 15,000				>15,000 to 20,000				>20,000 to 25,000				>25,000			
		Access Point Density, AP/mile																							
		<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30
4-ft Flush Median	<=5%	2.5	2.7	2.9	2.4	6.2	6.2	6.2	6.0	6.4	5.7	4.8	6.9	3.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>5% to <=10%	3.1	3.3	3.4	2.8	6.7	6.8	6.9	6.5	6.6	6.0	5.2	6.9	2.9	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>10% to <=15%	3.7	3.9	4.2	3.4	7.2	7.4	7.6	6.9	6.7	6.2	5.5	6.9	2.8	1.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>15% to <=20%	4.4	4.7	5.1	4.1	7.7	8.0	8.2	7.4	6.7	6.3	5.8	6.9	2.6	1.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>20%	5.3	5.6	6.1	4.9	8.2	8.5	8.9	7.8	6.7	6.5	6.0	6.9	2.5	1.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TWLTL	<=5%	N/A	N/A	N/A	N/A	3.6	3.4	3.2	3.7	7.6	7.5	7.2	7.6	12.4	12.4	12.1	12.2	17.7	17.8	17.7	17.3	23.5	23.8	23.8	22.9
	>5% to <=10%	1.3	1.3	1.2	1.3	4.7	4.8	4.7	4.6	8.7	8.8	8.9	8.4	12.9	13.2	13.4	12.5	17.4	17.8	18.1	16.8	22.0	22.6	23.1	21.2
	>10% to <=15%	2.0	2.0	2.0	1.8	5.7	5.9	6.0	5.4	9.3	9.7	10.0	8.9	13.0	13.5	13.9	12.4	16.6	17.3	17.9	15.9	20.2	21.1	21.8	19.3
	>15% to <=20%	2.6	2.7	2.9	2.5	6.4	6.8	7.1	6.1	9.7	10.2	10.7	9.2	12.7	13.4	14.0	12.1	15.6	16.4	17.1	14.8	18.3	19.2	20.1	17.3
	>20%	3.3	3.5	3.8	3.1	7.1	7.6	8.0	6.6	9.9	10.5	11.1	9.3	12.3	13.0	13.7	11.5	14.4	15.3	16.1	13.6	16.4	17.4	18.3	15.4
Non-traversable	<=5%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.8	2.9	2.9	2.8	6.0	6.3	6.5	5.7	9.6	10.1	10.7	9.0	13.6	14.5	15.4	12.8
	>5% to <=10%	N/A	N/A	N/A	N/A	1.3	1.3	1.2	1.3	3.6	3.7	3.9	3.4	6.2	6.6	6.9	5.9	9.1	9.7	10.3	8.6	12.2	13.0	13.9	11.4
	>10% to <=15%	N/A	N/A	N/A	N/A	2.0	2.1	2.2	2.0	4.1	4.3	4.6	3.9	6.3	6.7	7.1	5.9	8.5	9.1	9.7	8.0	10.8	11.6	12.4	10.1
	>15% to <=20%	N/A	N/A	N/A	N/A	2.7	2.8	3.0	2.5	4.5	4.8	5.1	4.2	6.2	6.7	7.1	5.8	7.9	8.5	9.1	7.4	9.6	10.3	11.1	8.9
	>20%	1.3	1.4	1.5	1.3	3.2	3.4	3.7	3.0	4.7	5.0	5.4	4.4	6.1	6.5	7.0	5.6	7.3	7.8	8.4	6.8	8.5	9.1	9.8	7.9

Notes: The base cross-section type is undivided roadways. Cells with "N/A" are estimated with BCRs under 1.0 (i.e., benefits < costs) which are not shown in the table. The results are applicable to roadways with posted speed limits of 50 mph and higher.

In highway project practices, some states use BCR ≥ 1 as the decision-making point, and some other states user higher BCRs (≥ 5) for safety projects. To be conservative, the team chose the BCRs ≥ 5 for recommendations. Based on Table 26, we developed preliminary criteria to recommend which cross-section (median type) is suitable for a traffic and road condition. The research team designed the following rules to recommend three cross-sections (over the undivided roadways) in each cell (representing a group of road/traffic conditions).

Undivided:

- Recommended – If a BCR for all three alternative cross-sections is under 3, the base cross-section (undivided roadway) is recommended.
- Microsimulation suggested – If a BCR for any one of alternative cross-sections is between 3 and 5.
- Not recommended – If a BCR for any one of alternative cross-sections is above 5.

4-ft Flush Median:

- Recommended – If a BCR for this cross-section type is greater than 5 and BCRs for the other two cross-sections are under 5.
- Microsimulation suggested – If a BCR for this cross-section type is between 3 and 5 (simulations for UR and segments with 4FMs), or if a BCR for any other cross-sections is also greater than 5 (simulations for segments with 4FMs and TWLTLs and/or NTMs).
- Not recommended – If a BCR for this cross-section type is under 5.

Two-Way Left-Turn Lane:

- Recommended – If a BCR for this cross-section type is greater than 5 and BCRs for the other two cross-sections are under 5.

- Microsimulation suggested – If a BCR for this cross-section type is greater than 5 and BCRs for the other two cross-sections are also greater than 5 (simulations for segments with TWLTLs and 4FMs and/or NTMs).
- Not recommended – If a BCR for this cross-section type is under 5.

Non-traversable Median:

- Recommended – If a BCR for this cross-section type is greater than 5 and BCRs for the other two cross-sections are under 5, or if the average daily traffic volume is greater than 20,000 vpd (considering the mobility needs of rural 4L roadways with NTMs).
- Microsimulation suggested – If the average daily traffic volumes are under 20,000 vpd, a BCR for this cross-section type is greater than 5 and BCRs for the other two cross-sections are also greater than 5 (simulations for segments with NTMs, 4FMs and/or TWLTLs).
- Not recommended – If a BCR for this cross-section type is under 5.

The following chart (Table 27) provides preliminary criteria for selecting an appropriate cross-section for rural 4L roadways. Note that, to ensure the consistency of recommendation, if a recommendation in one cell changes from one cross-section type to another, the recommendation would not reverse back to the previous cross-section recommendation. The chart provides recommendations for four typical cross-section types on rural four-lane roadways, including:

A. Four-Lane Undivided
B. Four-Lane Divided w/4-ft Flush Median
C. Four-Lane Divided w/TWLTL
D. Four-Lane Divided w/Non-Traversable Median or Barrier

When multiple letters (e.g., A/B, or B/C) are given in a cell, simulations are suggested to further examine and compare the performance of alternative cross-section designs. The performance may be examined from safety, mobility, and environmental aspects.

Table 27. Preliminary criteria for recommending cross-section on four-lane rural roadways.

Truck Percentage	Vehicle AADT																							
	<=5,000				>5,000 to 10,000				>10,000 to 15,000				>15,000 to 20,000				>20,000 to 25,000				>25,000			
	Access Point Density, AP/mile																							
	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30
<=5%	A	A	A	A	B	B	B	B	B/C	B/C	B/C	B/C	C/D	C/D	C/D	C/D	D	D	D	D	D	D	D	D
>5% to <=10%	A/B	A/B	A/B	A/B	B	B	B	B	B/C	B/C	B/C	B/C	C/D	C/D	C/D	C/D	D	D	D	D	D	D	D	D
>10% to <=15%	A/B	A/B	A/B	A/B	B/C	B/C	B/C	B/C	B/C	B/C	B/C	B/C	C/D	C/D	C/D	C/D	D	D	D	D	D	D	D	D
>15% to <=20%	A/B	A/B	A/B	A/B	B/C	B/C	B/C	B/C	B/C	B/C	B/C/D	B/C/D	C/D	C/D	C/D	C/D	D	D	D	D	D	D	D	D
>20%	B	B	B	B	B/C	B/C	B/C	B/C	B/C	B/C/D	B/C/D	B/C/D	C/D	C/D	C/D	C/D	D	D	D	D	D	D	D	D

Notes: A: Four-Lane Undivided

B: Four-Lane Divided w/4-ft Flush Median

C: Four-Lane Divided w/TWLTL

D: Four-Lane Divided w/Non-Traversable Median or Barrier

It is important to note that, the chart in Table 27 provides approximate cross-section recommendations merely based on the estimated crash reductions (by comparing the safety performance of a target cross-section with the base cross-section – four-lane undivided roadways), empirical crash costs, and project costs from the previous projects. The crash reduction estimation is based on the achieved crash data from 2013 to 2018 and sampled roadway segments. The results may change significantly when different years of data or roadway segments are selected in the analysis. The crash costs are also affected by numerous factors including economic inflation, which varies from time to time. The project cost is highly project-specific, and it can vary substantially from location to location in a state due to various factors including the prior conditions of a project site, local labor cost, and material cost, etc.

It is highly recommended that decision-makers or practitioners use the safety benefits from Table 24 to compare with the cost of a specific proposed project and make a more realistic recommendation of the cross-section type. Also, Table 24 includes only the safety benefits, other benefits such as mobility and environmental benefits also need to be considered in the decision-making process.

Application of access management principles such as consolidation of driveways to a single point where auxiliary lanes may be provided to reduce access point density. Roadway intersections and higher volume driveways should be provided with auxiliary lanes per adopted warranting criteria, see Section 7.4 of the GDOT Design Policy Manual (GDOT, 2019c). Where provided, depressed median widths should follow Section 6.12 of the GDOT Design Policy Manual (GDOT, 2019c).

Chapter 9: GUIDELINES for MICROSIMULATION

Microsimulation helps to evaluate the impact of different access management practices on the operation and safety of the network. FHWA has created "*Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*" to assist practitioners in assessing traffic performance (Wunderlich et al., 2019). The team extracted high-level information from this document and presented it in a simple and concise manner. For additional details, the above-mentioned document should be referenced.

The overall process for developing and applying a microsimulation model to a specific transportation analysis problem consists of the following seven major steps, as shown in Figure 23:

Step 1 – Microsimulation Analysis Planning

- In planning phase, the research questions that need to be answered through simulation should be phrased. In this context, an example question will be:
    - Which cross-section provides improved traffic performance for the given traffic and road conditions?
- An effective plan should include study "scope/objectives, hypotheses, performance measures, scope, technical approach, and an estimate of resources required for the study".
- Performance measures such as delay, queue length, travel time, average speed, etc. could be used. It would be better to consider measures that could be easily captured in the microsimulation models.
- Once the study objectives and performance measures have been identified, the next step is to identify the scope - both in terms of geographic and temporal limits.

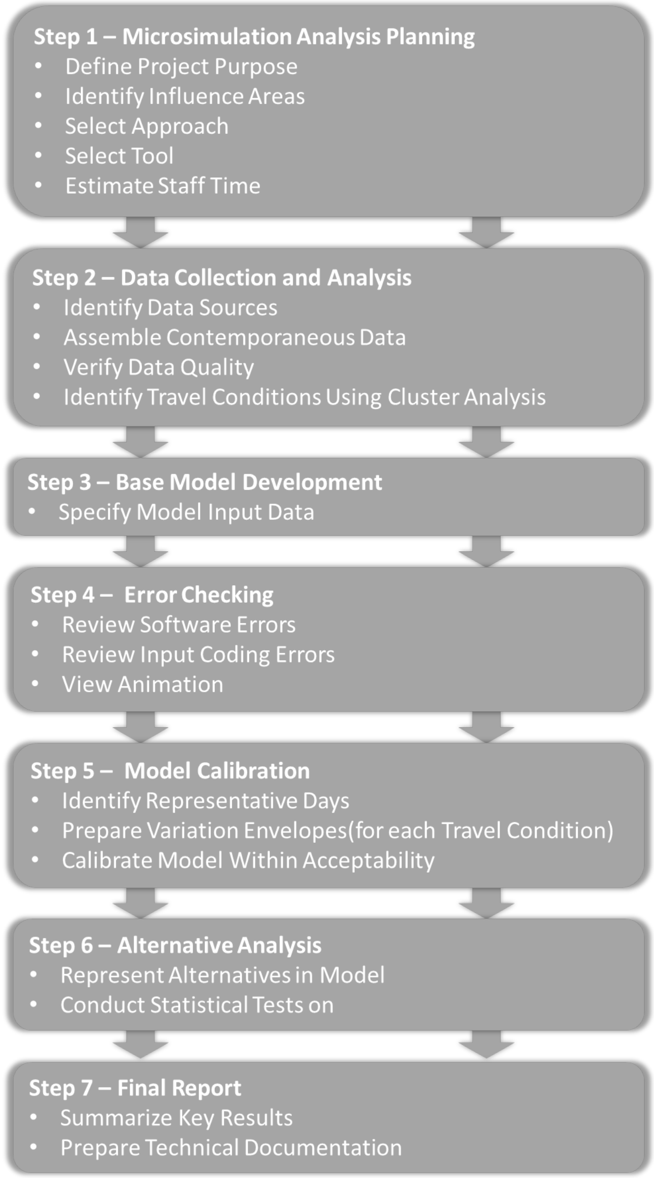


Figure 23. Seven Key Steps in Microsimulation Analysis (Wunderlich et al., 2019).

- Microsimulation models are data-intensive. They take more effort than macroscopic simulation models (e.g., transportation planning models). The model results are sensitive to different vehicle performance characteristics and differing driver behavior characteristics.

- The resource requirements for the development, calibration, and application of microsimulation models will vary according to the complexity of the project, its geographic scope, temporal scope, number of alternatives, and the availability and quality of the data. Adequate time should also be allotted to conduct a successful analysis. Data collection, coding, error checking, and calibration are critical tasks for completing a calibrated model.

Step 2 – Data Collection & Analysis

- This step is to identify data sources and gather data needed to develop a microsimulation model for a specific project analysis. In this project, typical data elements include:
    - Road geometry (number of lanes, lane widths, segment length, shoulder type, shoulder width, slope, curvature, etc.)
    - Access management (median type, median width, access points, turn lanes, pavement markings, etc.)
    - Traffic volume or travel demand (AADT, truck percentages, turning volumes)
    - Traffic controls (speed limit sign, stop sign, yield sign, signals, pavement marking, etc.)
    - Vehicle characteristics (vehicle mix, vehicle dimensions, and vehicle performance characteristics e.g., maximum acceleration).
    - Driver characteristics (driver aggressiveness, reaction time, desired speeds, and acceptable critical gaps for lane changing, merging and crossing).
- If the alternatives are to be evaluated in target future year (especially for major construction projects, e.g., road widening), forecasted data needs to be procured, such as the travel demand. Local metropolitan planning organization (MPO) travel demand models can provide travel demand data for future years.

- Additional data may be needed for model calibration. Calibration is the process of systematically adjusting model parameters so that the model emulates observed traffic conditions in the study area.
- It is important to note that, data quality needs to be checked before using it. The data error checking can be done by field inspection and surveys.

Step 3 – Base Model Development

- When resources are constrained, it may not be cost-effective to model every condition. A base model is developed to represent the most typical conditions. The base model is used to compare the travel conditions where alternatives (e.g., two cross-sections) are likely to have significant impacts.
- While developing the base model, Default values can be assumed for driver behavior, gap acceptance, etc. as it is hard to obtain this information. Any assumptions, default values, or deviations from default values should be discussed and documented.
- The link-node diagram is the blueprint for constructing the microsimulation model. The diagram identifies which streets and highways will be included in the model and how they will be represented.
- A route needs to be created (as it is in the field) or imported into the microsimulation software. Road geometry (number of lanes, lane widths, etc.), traffic volume, and signage information are assigned to the designed route.

Step 4 – Error Checking

- The error correction step is essential in developing a working model so that the calibration process does not result in parameters that are distorted to compensate for overlooked coding errors.

- Error checking involves various reviews of the coded network, coded demand, and default parameters.
- The analyst should review the software and user group web sites to ensure that he or she is aware of the latest known "bugs" and user workarounds for the software. The analyst should ensure that he or she is using the latest version and "patch" of the software, if any.
- There might be errors in the input data, such as the network connectivity, link attributes (e.g., free-flow speed, facility type, lane numbers, etc.), traffic controls, vehicle mix proportions, percentages of truck volumes and turn movements in traffic, Driver behavior and vehicle characteristics.
- Animation output enables the analyst to see the vehicle behavior that is being modeled and assess the reasonableness of the microsimulation model itself. A two-stage process can be followed in reviewing the animation output. Run the animation at an extremely low demand level (so low that there is no congestion). Once the extremely low demand level tests have been completed, then run the simulation at 50 percent of the existing demand level.

Step 5 – Model Calibration

- It is important to check if the developed model can represent the field. If not, the model parameters need to be changed (within a defined range) until the model is comparable.
- The model calibration is also to ensure that the microsimulation model will function as an accurate predictor of transportation system performance in alternatives analysis.
- Every microsimulation software program comes with a set of user-adjustable parameters for the purpose of calibrating the model to local conditions. Therefore, the objective of

calibration is to find the set of parameter values for the model that best reproduces observed measures of system performance.

- An effective calibration requires at least two key performance measures. Travel time or speed could be used as calibration parameters for 4L rural roadways.

Step 6 – Alternatives Analysis

- The objective of this project is to evaluate different median alternatives on 4L roadways. Multiple microsimulations run by varying random number seeds must be performed for each design alternative and the outcomes need to be captured.
- Some analyses require the explicit consideration of system performance in future years. In these cases, the analyst should make a forecast of future year travel demand. Forecasts of future travel demand significantly different from current conditions are best obtained from a travel demand model developed and maintained by the local metropolitan planning organization.
- Statistical methods (e.g., Welch's t-test) could be used to test a significant difference in the performance of the design alternatives.
- A sensitivity analysis is a targeted assessment of the reliability of the microsimulation results, given the uncertainty in the input or assumptions. The analyst identifies certain input or assumptions about which there is some uncertainty and varies them to see what their impact might be on the microsimulation results.

Step 7 – Final Report

- Making a clear and concise presentation of analytical findings is a critical element of a successful microsimulation analysis.
- The results from the microsimulation could be summarized and reported as needed.

- The report should begin with the analytical objective and the context of the study.
- While preparing the final report, it is important to remember your audience and clarify what was analyzed and not analyzed.

Microsimulation can provide the analyst with valuable information on the performance of the existing transportation system and potential improvements. However, microsimulation can also be a time-consuming and resource-intensive activity. It is recommended that the operational performance will be evaluated only in conditions when the safety outcomes of the two proposed alternatives are relatively unclear. This project provides criteria for the median uses on the rural 4L segments and the criteria are based on the traffic volumes (AADT), truck percentage, and access point density. According to the criteria chart in Table 27, there are cases that the microsimulation may be conducted to assist the decision-making of cross-section selection. The simulation results can offer insights into other performance measures (besides the crash outcomes), such as delay, queue length, travel time, etc.

Chapter 10: SUMMARY & CONCLUSIONS

NTMs mostly yield improved safety performance compared to other median types such as undivided, 4FM, TWLTL. However, constructing NTMs is costly because of the extra right-of-way that needs to be procured and additional construction costs involved. The goal of this study is to identify cost-effective median types, that maximize safety benefits, for four-lane rural roads in Georgia for a given set of roadway and traffic conditions. The authors thus came up with a criterion to determine under what conditions these four median types yield maximum safety benefits while considering the cost of construction.

Extensive data cleaning and manipulation were adopted to refine the data. Data were pooled from various sources such as GDOT, FHWA, and Google maps. Traffic volume data, crash data, roadway data, etc. were merged using several tools. Manual data extractions were also performed because of the lack of data such as access points. Also, manual verification of median types was carried out to ensure the authors include the right section in the desired median type.

Safety performance functions and Crash modification factors were used to create the criteria. SPFs were developed for all the four median types that were considered in the study. AADT, truck percentage, and access point density were considered as independent variables in the SPFs. SPFs were developed for different crash-severity combinations; eventually, KAB severities were used in the final criteria development as they are believed to influence the benefits (in terms of crash costs). The CMFs are calculated to show the effectiveness of a cross-section compared to the base cross-section which is a 4L-UR. CMFs are likely to vary across different values of AADT, segment length, truck percent, and access point density, indicating that the safety effectiveness of a treatment on roadways is likely to vary across different situations. This study predicted the crash frequencies for one mile of segments. CMFs are estimated by keeping one of the factors (AADT, truck percent, access point density) constant and varying the other two factors. CMFs were calculated for typical values of AADT, truck percentage, and access point density. The key findings based on CMFs are as follows:

- The segments with NTMs outperform the other three segment types across all AADTs, truck percentages and access point densities, except at very low AADT around or lower than 5,000 where the 4FMs appear to be associated with an improved condition.
- AADT – Is a principal factor to show the effectiveness of a cross-section compared to the base. In general, the 4FMs appear to have an improved performance than UR segments when the AADT is low (around or lower than 10,000); when the AADT increases (around or higher than 10,000), the TWLTLs have an improved performance than UR section and 4FMs; when the AADT reaches 20,000, the NTMs may be considered.
- Truck percentage – Is positively related to the safety effectiveness of 4FM, TWLTLs and NTMs compared to the base segment type. In other words, converting a 4L-UR segment into one of other three cross-section types can result in an even further improved condition for traffic with a higher truck percentage.
- Access point density – Is negatively related to the safety effectiveness of 4FMs, TWLTLs and NTMs compared to the base segment type. In other words, the safety effectiveness of these three types of medians decreases with the increase in the number of access points along a segment.

Note that, the safety performance on roadways may be associated with the posted speed limits. The estimation of SPFs/CMFs in this study did not consider the impact of speed limits. According to a preliminary study in Appendix A, a higher speed limit is likely associated with a greater rate for fatal and serious injury crashes.

Besides estimating CMFs, to facilitate criteria development and make recommendations on median type, the authors estimated average annual crash reductions (compared with URs). These crash reductions were converted into monetary values using the average crash costs by severities. The safety benefits (shown below) and the project costs could be used to estimate benefit-cost ratios.

Safety Benefits (in $million) for 4FMs, TWLTLs, and NTMs compared with URs as the base.

	Truck Percentage	Vehicle AADT																							
		<=5,000				>5,000 to 10,000				>10,000 to 15,000				>15,000 to 20,000				>20,000 to 25,000				>25,000			
		Access Point Density, AP/mile																							
		<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30
4-ft Flush Median	<=5%	$7	$7	$8	$6	$16	$17	$17	$16	$17	$15	$13	$18	$8	$2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>5% to <=10%	$8	$9	$9	$8	$18	$18	$18	$17	$17	$16	$14	$18	$8	$3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>10% to <=15%	$10	$10	$11	$9	$19	$20	$20	$18	$18	$16	$15	$18	$7	$3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>15% to <=20%	$12	$12	$13	$11	$20	$21	$22	$20	$18	$17	$15	$18	$7	$3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>20%	$14	$15	$16	$13	$22	$23	$24	$21	$18	$17	$16	$18	$7	$3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TWLTL	<=5%	$3	$2	$2	$3	$14	$14	$13	$15	$30	$30	$29	$30	$49	$49	$48	$49	$71	$71	$70	$69	$93	$95	$95	$91
	>5% to <=10%	$5	$5	$5	$5	$19	$19	$19	$18	$35	$35	$35	$34	$51	$53	$53	$50	$69	$71	$72	$67	$87	$90	$92	$84
	>10% to <=15%	$8	$8	$8	$7	$23	$23	$24	$22	$37	$39	$40	$36	$52	$54	$56	$49	$66	$69	$71	$63	$80	$84	$87	$77
	>15% to <=20%	$10	$11	$11	$10	$26	$27	$28	$24	$39	$41	$43	$37	$51	$53	$56	$48	$62	$65	$68	$59	$73	$77	$80	$69
	>20%	$13	$14	$15	$12	$28	$30	$32	$26	$39	$42	$44	$37	$49	$52	$55	$46	$57	$61	$64	$54	$65	$69	$73	$61
Non-traversable	<=5%	N/A	N/A	N/A	N/A	$3	$2	$1	$3	$19	$20	$20	$19	$41	$43	$44	$39	$66	$70	$73	$62	$93	$99	$106	$87
	>5% to <=10%	N/A	N/A	N/A	N/A	$9	$9	$9	$9	$25	$26	$26	$23	$43	$45	$48	$40	$62	$66	$71	$59	$83	$89	$95	$78
	>10% to <=15%	$2	$2	$2	$2	$14	$15	$15	$13	$28	$30	$31	$27	$43	$46	$49	$40	$59	$63	$67	$55	$74	$80	$85	$69
	>15% to <=20%	$6	$6	$6	$5	$18	$19	$20	$17	$31	$33	$35	$29	$43	$46	$49	$40	$54	$58	$62	$51	$66	$71	$76	$61
	>20%	$9	$10	$10	$9	$22	$24	$25	$20	$32	$35	$37	$30	$42	$45	$48	$39	$50	$54	$58	$47	$58	$62	$67	$54

Notes: The base cross-section type is undivided roadways. The safety benefits cover reductions in all crash types. The safety benefits of 20 years are estimated. Cells with “N/A” are estimated with negative safety benefits. The results are applicable to roadways with posted speed limits of 50 mph and higher.

The research team gathered project costs from GDOT and several openly available sources and estimated BCRs considering the upper bound of the project costs and came up with the following criteria.

Preliminary criteria for recommending cross-section on four-lane rural roadways.

Truck Percentage	Vehicle AADT																							
	<=5,000				>5,000 to 10,000				>10,000 to 15,000				>15,000 to 20,000				>20,000 to 25,000				>25,000			
	Access Point Density, AP/mile																							
	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30
<=5%	A	A	A	A	B	B	B	B	B/C	B/C	B/C	B/C	C/D	C/D	C/D	C/D	D	D	D	D	D	D	D	D
>5% to <=10%	A/B	A/B	A/B	A/B	B	B	B	B	B/C	B/C	B/C	B/C	C/D	C/D	C/D	C/D	D	D	D	D	D	D	D	D
>10% to <=15%	A/B	A/B	A/B	A/B	B/C	B/C	B/C	B/C	B/C	B/C	B/C	B/C	C/D	C/D	C/D	C/D	D	D	D	D	D	D	D	D
>15% to <=20%	A/B	A/B	A/B	A/B	B/C	B/C	B/C	B/C	B/C	B/C	B/C/D	B/C/D	C/D	C/D	C/D	C/D	D	D	D	D	D	D	D	D
>20%	B	B	B	B	B/C	B/C	B/C	B/C	B/C	B/C/D	B/C/D	B/C/D	C/D	C/D	C/D	C/D	D	D	D	D	D	D	D	D

Notes: A: Four-Lane Undivided

B: Four-Lane Divided w/4-ft Flush Median

C: Four-Lane Divided w/TWLTL

D: Four-Lane Divided w/Non-Traversable Median or Barrier

When multiple letters (e.g., A/B, or B/C) are given in a cell, simulations are suggested to further examine and compare the performance of alternative cross-section designs. The performance may be examined from safety, mobility, and environmental aspects. It is important to note that, the criteria table provides rough cross-section recommendations merely based on the estimated crash reductions, empirical crash costs, and project costs from the previous projects. The project cost is project-specific, and it can vary substantially from location to location in a state due to various factors including the prior conditions of a project site, local labor cost, and material cost, etc. It is recommended that decision-makers or practitioners use the safety benefits table to compare with the cost of a specific proposed project and make a more realistic recommendation of the cross-section type.

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APPENDIX A. Speed and Safety Performance on Rural Four-lane Roadways.

This appendix provides some quick results on the relationship between the posted speed limits and safety performance on rural four-lane roadways in Georgia. The safety performance on roadways may be associated with the posted speed limits. We linked the roadway segments sampled in this project with the speed limit information in the Highway Performance Monitoring Database. Four types of cross-sections were investigated:

1. *Four-lane Undivided*
2. *Four-lane Divided w/4-ft. flush paved median*
3. *Four-lane Divided w/Two-Way Left-Turn Lane*
4. *Four-lane Divided w/Non-traversable median or median barrier*

Table A-1 shows the numbers of observations for four cross-section types under three possible speed limits. Note, the scope of this project is limited to high-speed rural roadways, > 45 mph. In the sampled segments, there is no observation for Undivided, 4-ft Flush Median and TWLTL with a speed limit of 65 mph. The analysis is limited to the observation available in sampled roadway segments.

Table A-1. Number of observations.

	Speed Limit	Number of observations (segments)
		Total
Undivided	**50**	54
	55	25
4-ft Flush Median	**50**	19
	55	146
TWLTL	**50**	103
	55	455
Non-Traversable	**50**	22
	55	783
	65	369

The crash rate for each segment is estimated using the equation below:

$$CR_{VMT} = \frac{C \times 100{,}000{,}000}{AADT \times 365 \times N \times L} \tag{1}$$

where,

CR_{VMT} = Crash rate per 100-million VMT;

C = Total number of crashes in the 6-year study period;

$AADT$ = Average Traffic volume using Annual Average Daily Volumes (AADT) in the 6-year study period;

N = Total number of years in the study period; and

L = Length (in miles) of the roadway segment.

Note that, the crash rates can be sensitive to the exposure that includes the traffic volume and the segment length. For segments with small exposures (low AADT and short segment), the crash rates can be extreme especially with a limited number of observations. To show an unbiased comparison of safety performance across observations of different exposures, the crash rates are weighted by the exposure (AADT × Segment Length). In other words, observations with greater exposure are weighted more in the average weighted crash rates for a segment group. Table 2 shows the weighted crash rates for four types of cross-sections under different speed limits. In addition to the rates for total crashes, Table A-2 also shows the rates for different crash severities including:

- *K – Fatal Injury*
- *A – Suspected Serious injury*
- *B – Suspected Minor or Visible Injury*
- *C – Possible Injury or Complaint*
- *O – No Apparent Injury*

Table A-2. Weighted crash rates (per 100 million vehicle miles).

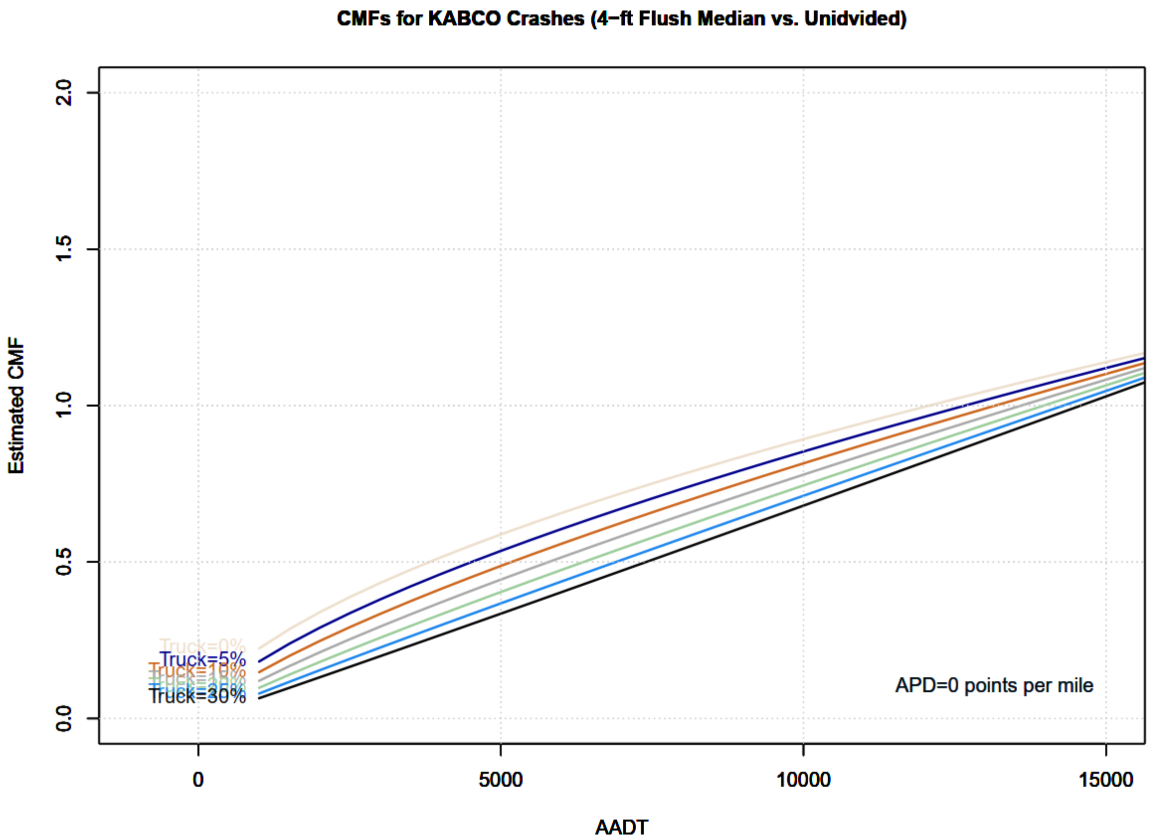
	Speed Limit	Weighted* crash rate (per 100 million vehicle miles)					
		Total	**K**	**A**	**B**	**C**	**O**
Undivided	**50**	93.005	2.608	16.225	10.430	10.430	57.367
	55	107.730	2.284	19.414	11.420	11.420	64.334
4-ft Flush Median	**50**	60.604	0.522	9.404	4.180	4.180	33.959
	55	97.653	1.196	13.508	12.664	12.664	63.742
TWLTL	**50**	87.440	1.154	9.575	7.960	7.960	58.485
	55	93.683	1.277	9.795	10.144	10.144	63.833
Non-Traversable	**50**	93.079	1.103	5.294	7.940	7.940	66.611
	55	61.719	0.807	9.014	7.127	7.127	40.798
	65	55.682	1.012	8.332	6.796	6.796	36.342

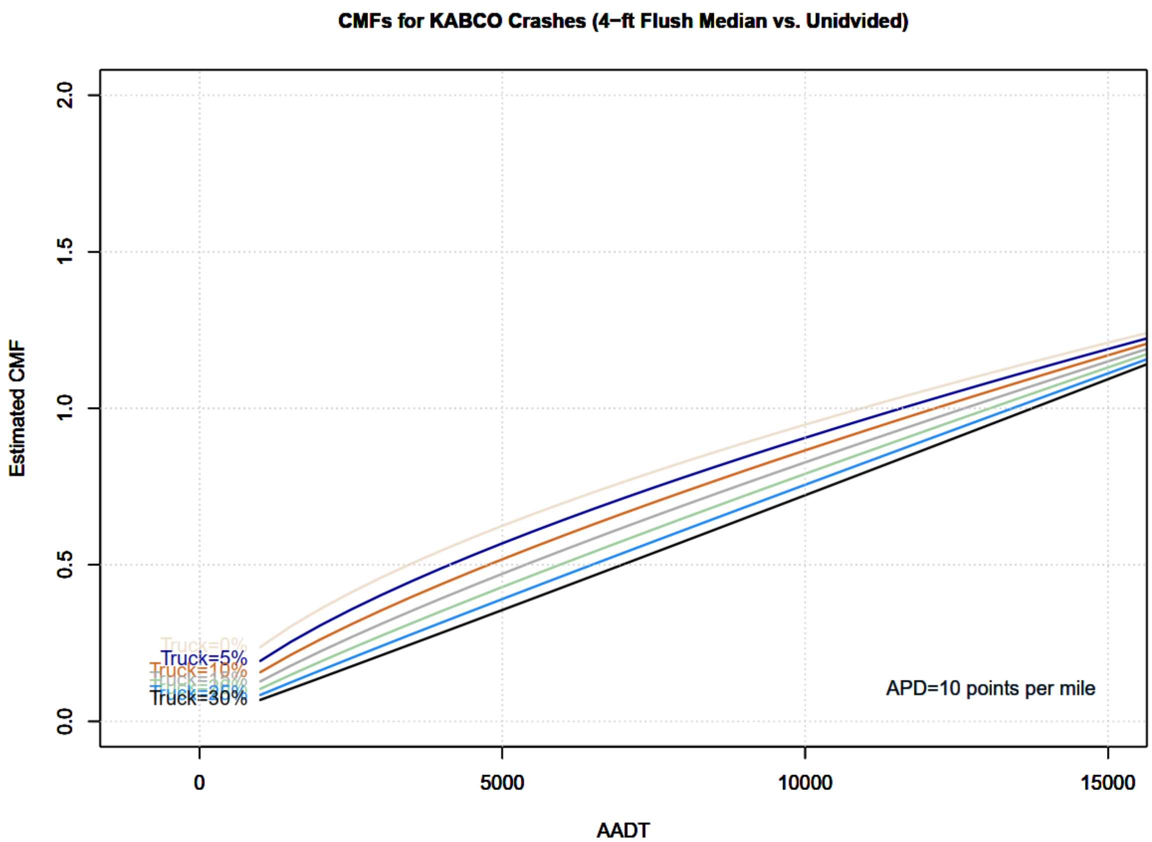
*Weighted by AADT × Segment Length

The results show that the total crash rates are greater for higher speed limits for the first three cross-sections (Undivided, 4-ft Flush Median, and TWLTL), and the total crash rates drop for higher speed limits for the last cross-section type with non-traversable medians. Across all four sections, it seems that a higher speed limit is associated with a greater rate for crashes of high severities (K and A).

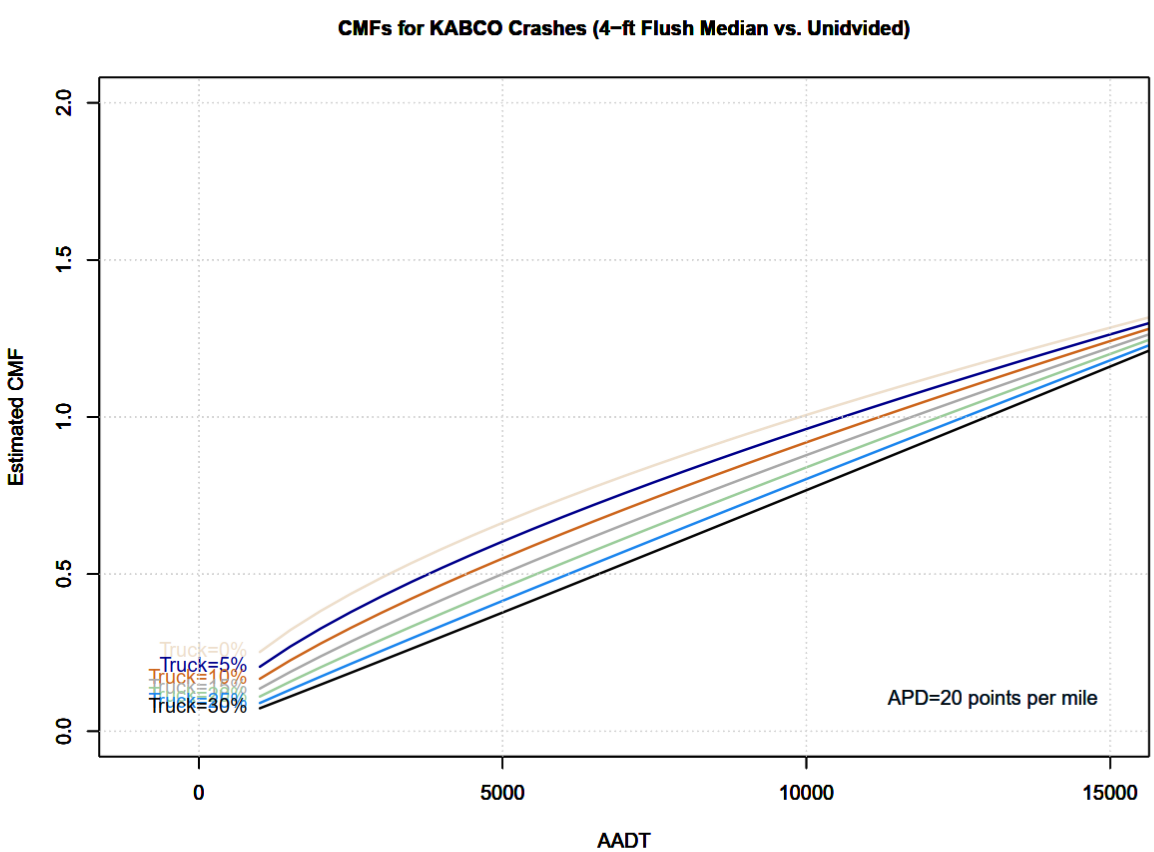
Note that, the results are limited to the available observations in the sampled roadway segments. Further, the highway safety performance can be affected by many factors, and the results presented in this document are not intended to attribute the crash rate differences to speed limit only. For example, for a given 50 mph non-traversable roadway we may experience a higher rate than the 65 mph roadways if we consider certain conditions that may exist on those segments, such as a greater number of driveways/intersections, horizontal/vertical alignment changes that are more pronounced on the lower speeds, and other characteristics (lighting, shoulder widths, land use, etc.). Therefore, a comprehensive investigation would be needed to uncover the complete picture of contributing factors of safety performance on roadways.

APPENDIX B. CMF Plots along AADT for different Truck Percentages and Access Point Densities.

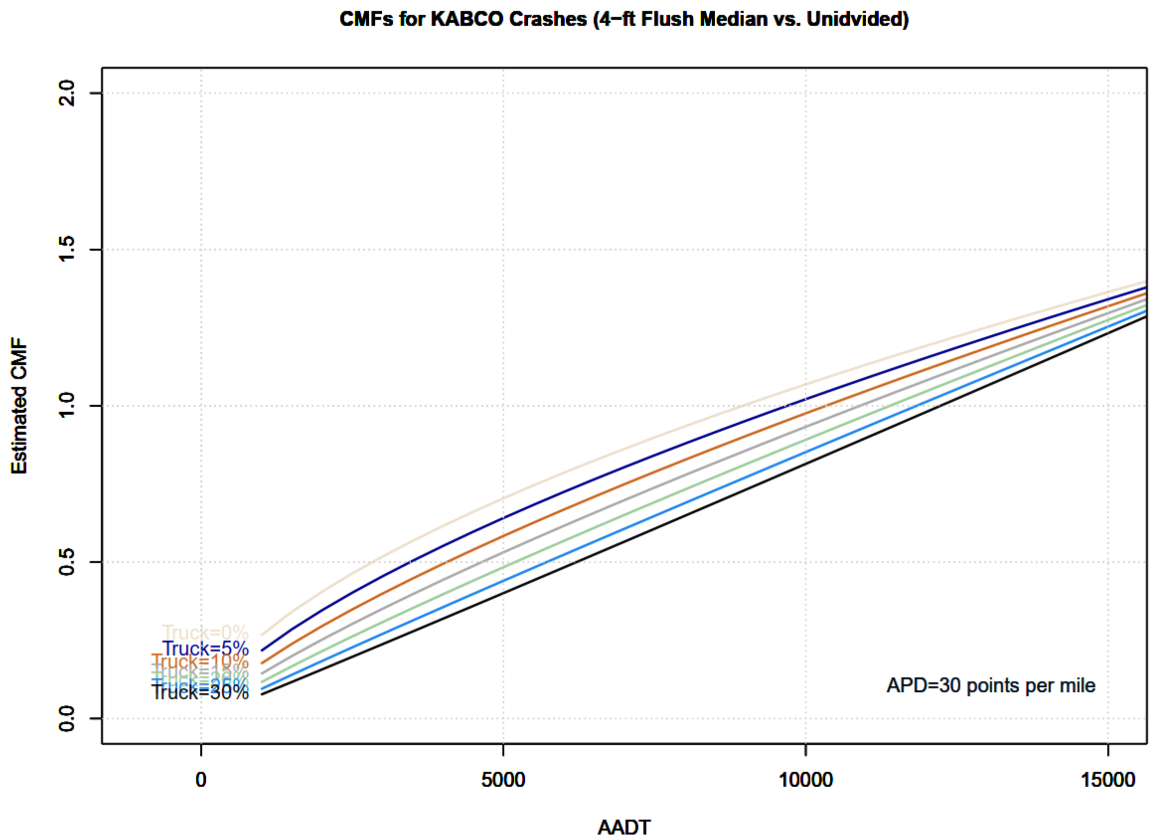


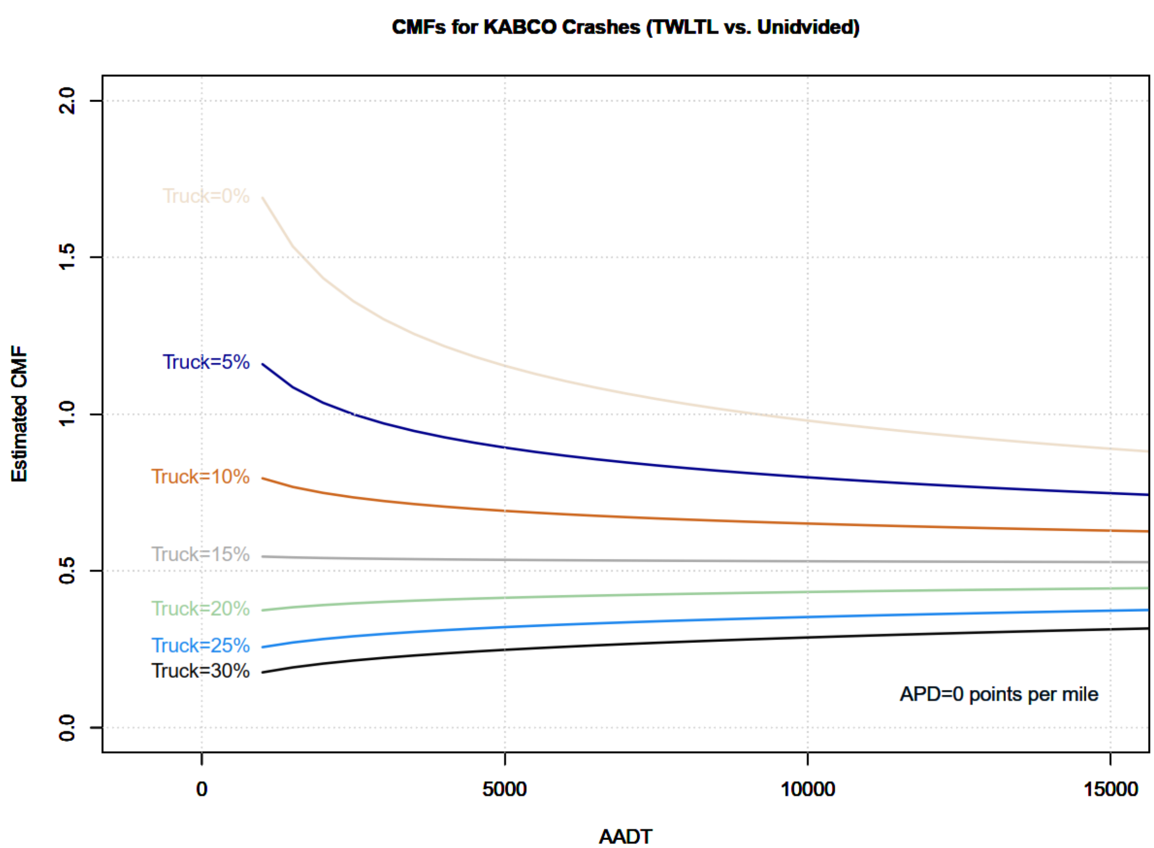


CMFs for KABCO Crashes (4−ft Flush Median vs. Unidvided)
Estimated CMF
AADT
Truck=0%
Truck=5%
Truck=10%
Truck=30%
APD=10 points per mile



CMFs for KABCO Crashes (4−ft Flush Median vs. Unidvided)
Estimated CMF
AADT
Truck=0%
Truck=5%
Truck=10%
Truck=30%
APD=20 points per mile


CMFs for KABCO Crashes (4−ft Flush Median vs. Unidvided)
Estimated CMF
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000
AADT
Truck=0%
Truck=5%
Truck=10%
Truck=30%
APD=30 points per mile


CMFs for KABCO Crashes (TWLTL vs. Unidvided)
Estimated CMF
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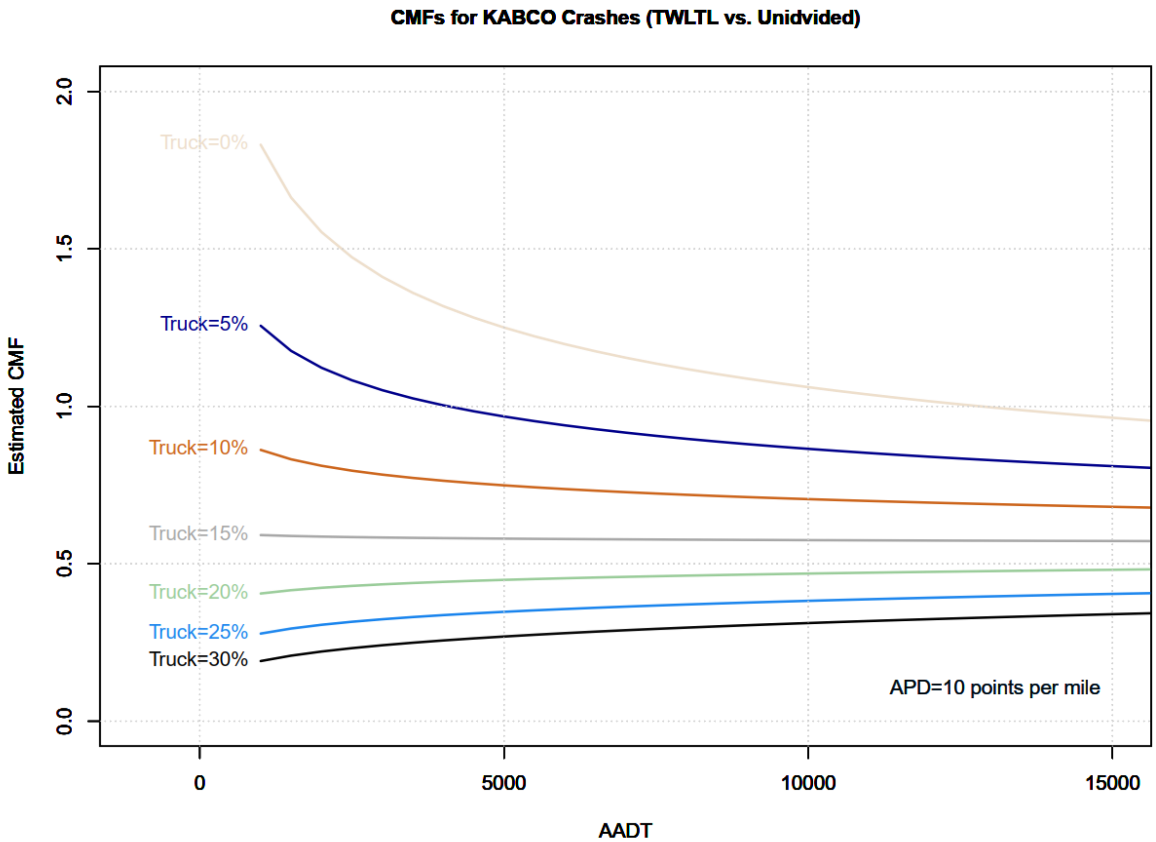
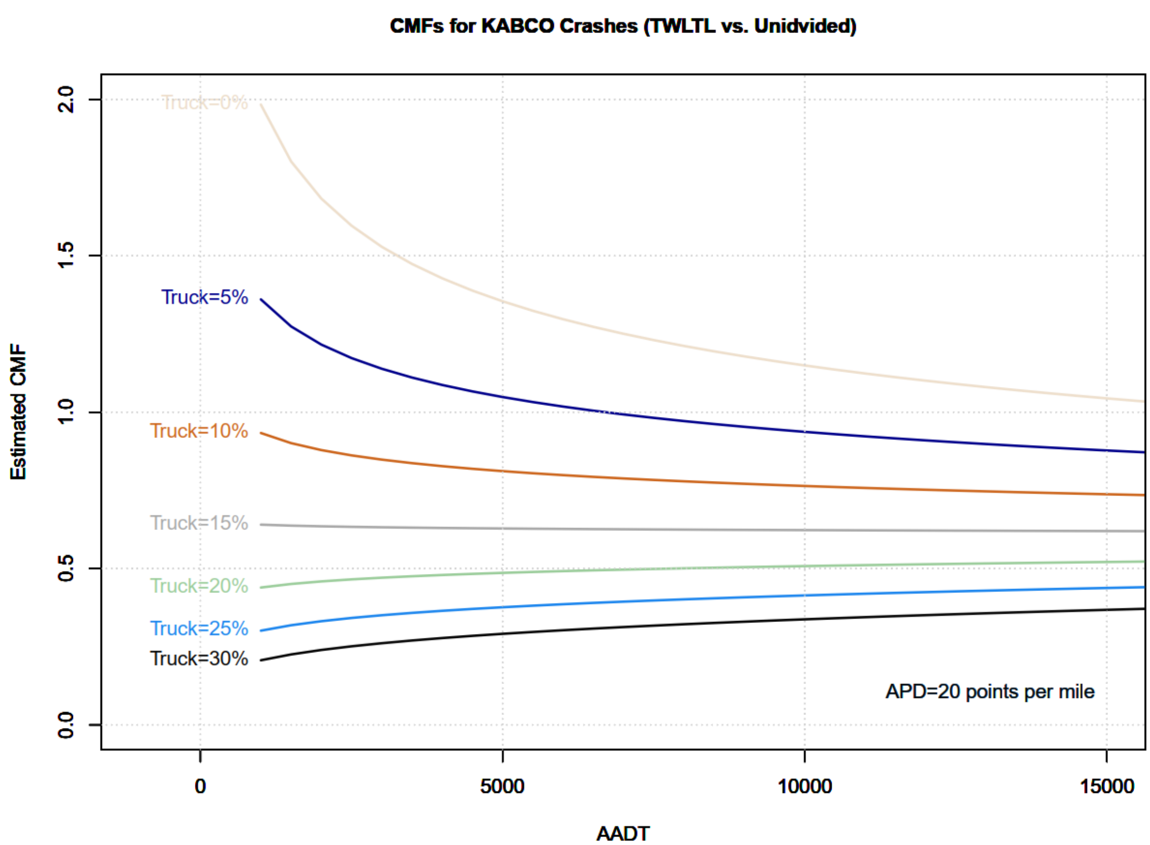
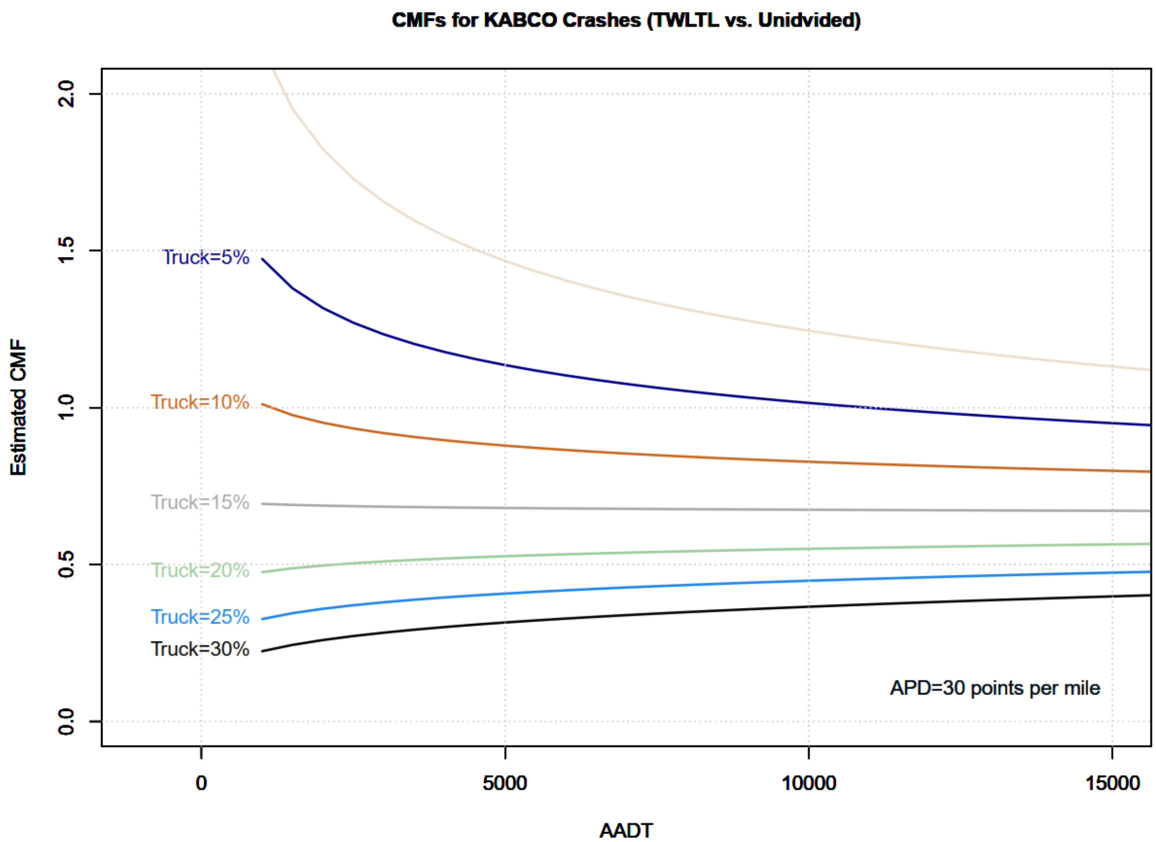
0.5
1.0
1.5
2.0
0
5000
10000
15000
AADT
Truck=0%
Truck=5%
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=0 points per mile

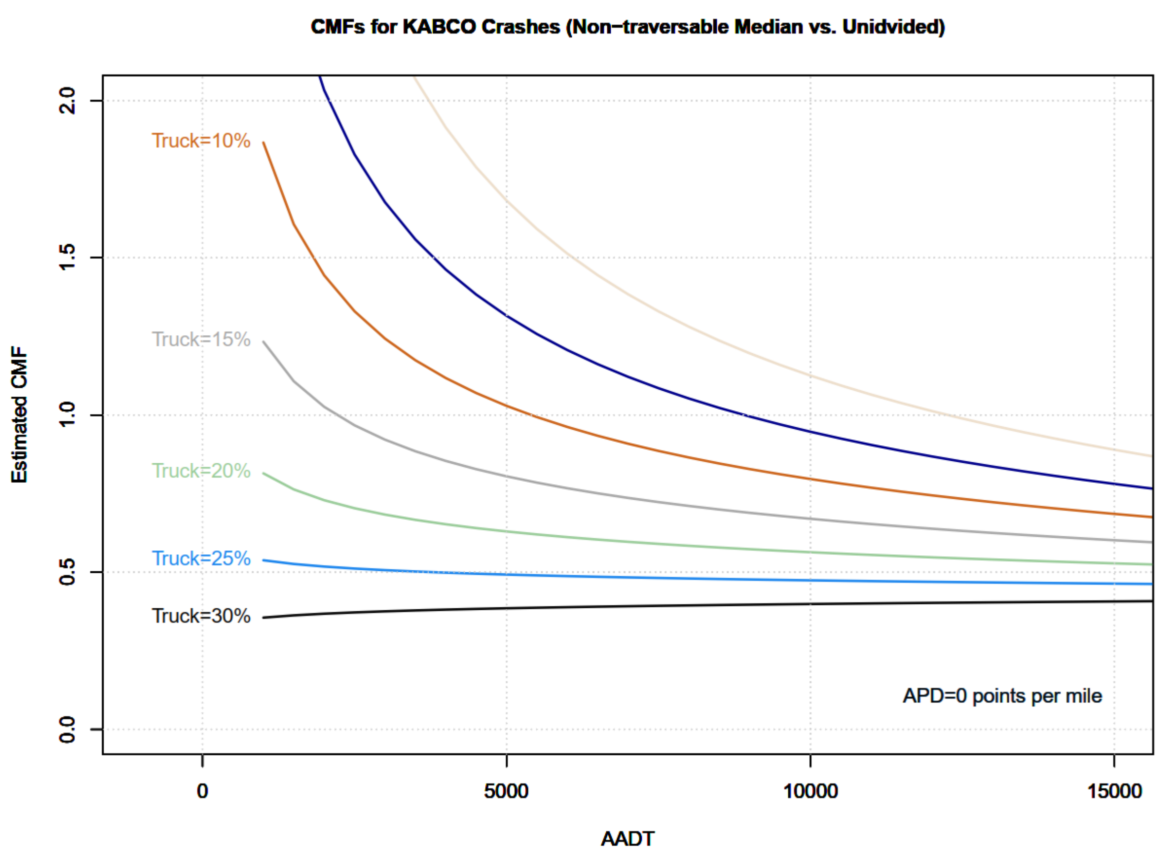


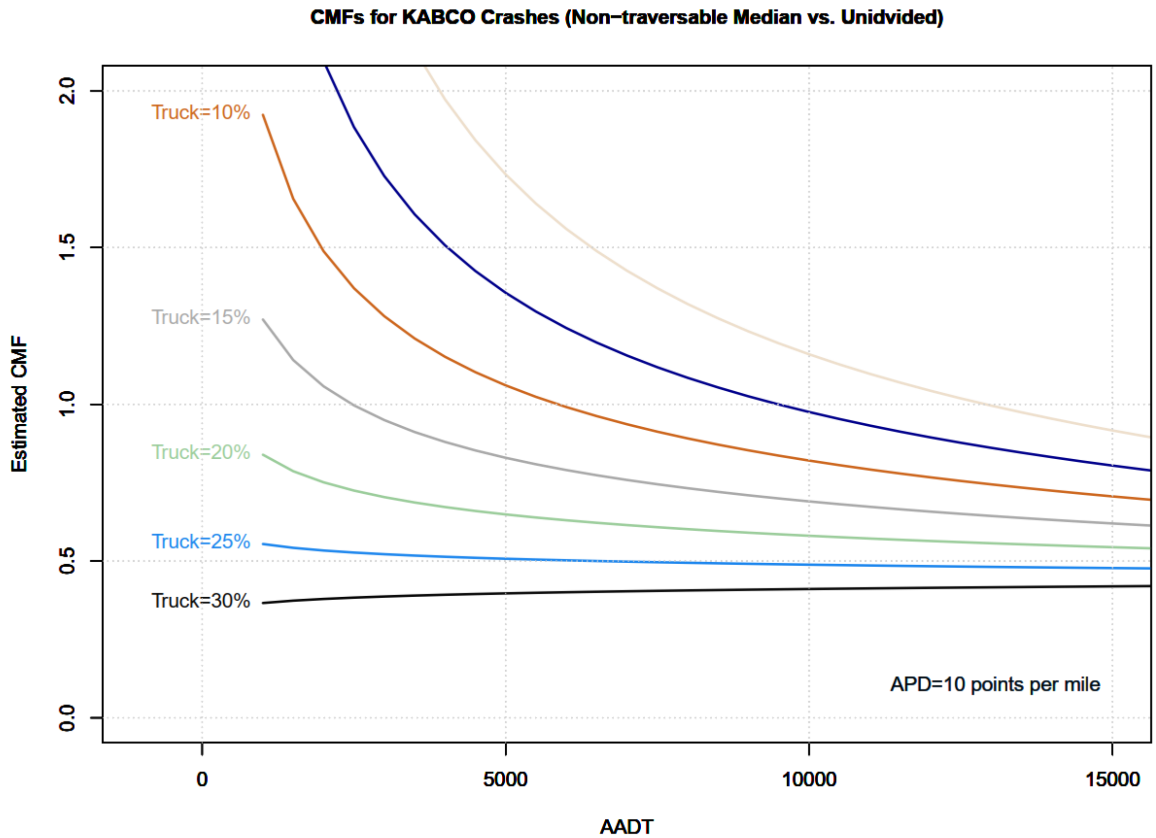
CMFs for KABCO Crashes (TWLTL vs. Unidvided)
Estimated CMF
AADT
Truck=0%
Truck=5%
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=10 points per mile
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000

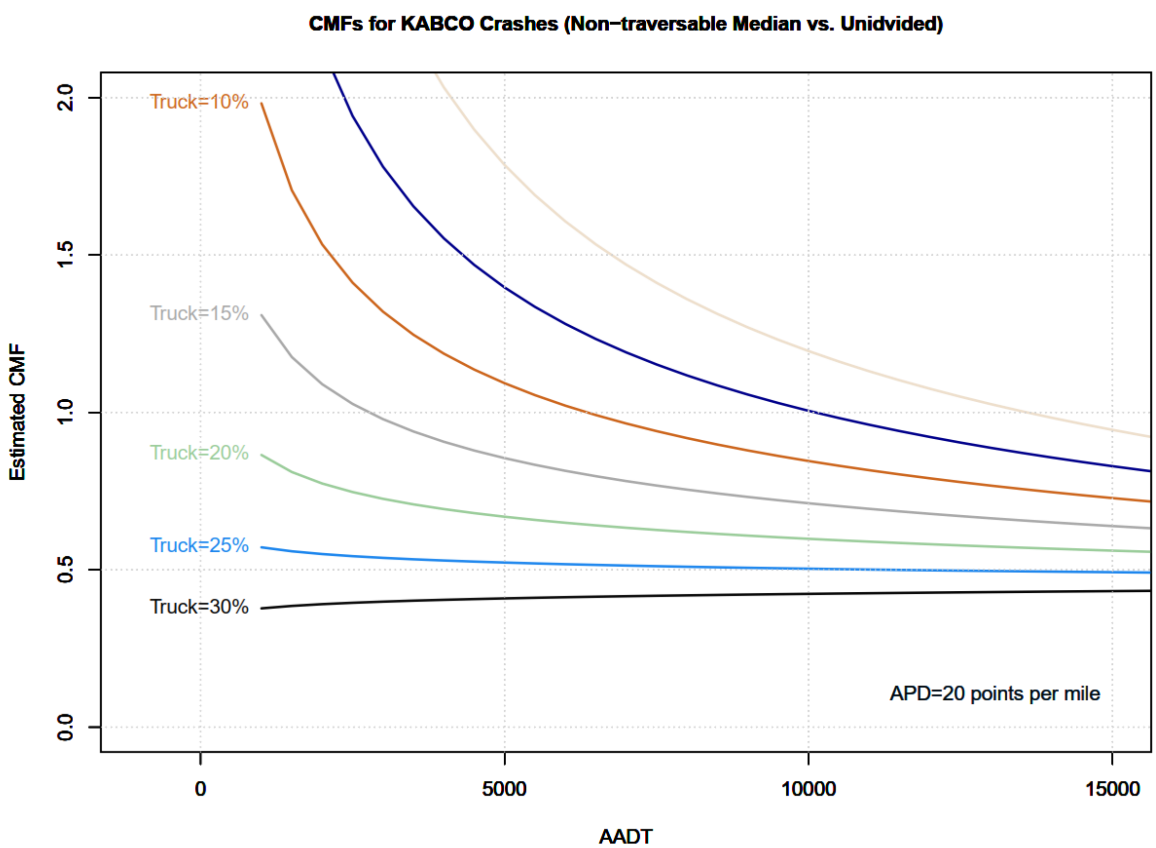


CMFs for KABCO Crashes (TWLTL vs. Unidvided)
Estimated CMF
AADT
Truck=0%
Truck=5%
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=20 points per mile
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000


CMFs for KABCO Crashes (TWLTL vs. Unidvided)
Estimated CMF
2.0
1.5
1.0
0.5
0.0
Truck=5%
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=30 points per mile
0
5000
10000
15000
AADT


CMFs for KABCO Crashes (Non−traversable Median vs. Unidvided)
Estimated CMF
2.0
1.5
1.0
0.5
0.0
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=0 points per mile
0
5000
10000
15000
AADT


CMFs for KABCO Crashes (Non−traversable Median vs. Unidvided)
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=10 points per mile
Estimated CMF
AADT
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000


CMFs for KABCO Crashes (Non−traversable Median vs. Unidvided)
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=20 points per mile
Estimated CMF
AADT
0.0
0.5
1.0
1.5
2.0
0
5000
10000
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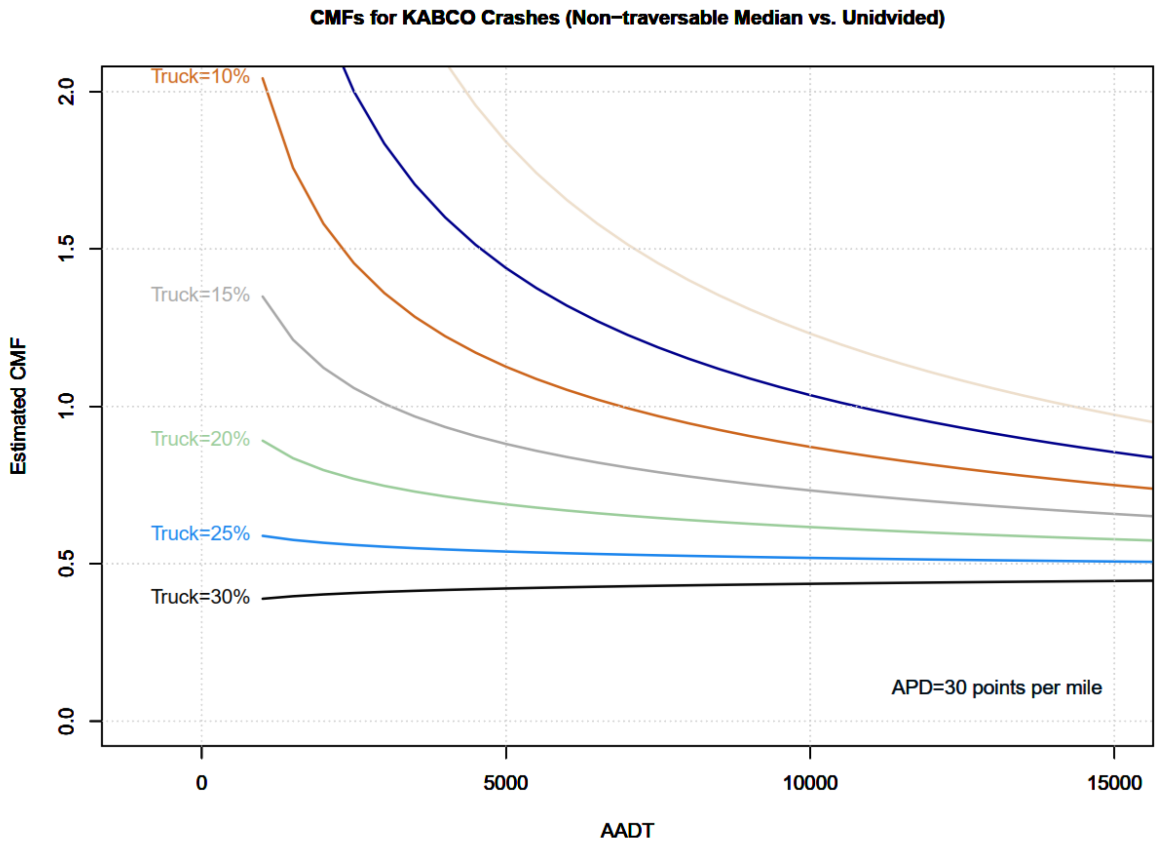
CMFs for KABCO Crashes (Non−traversable Median vs. Unidvided)
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=30 points per mile
Estimated CMF
0.0
0.5
1.0
1.5
2.0
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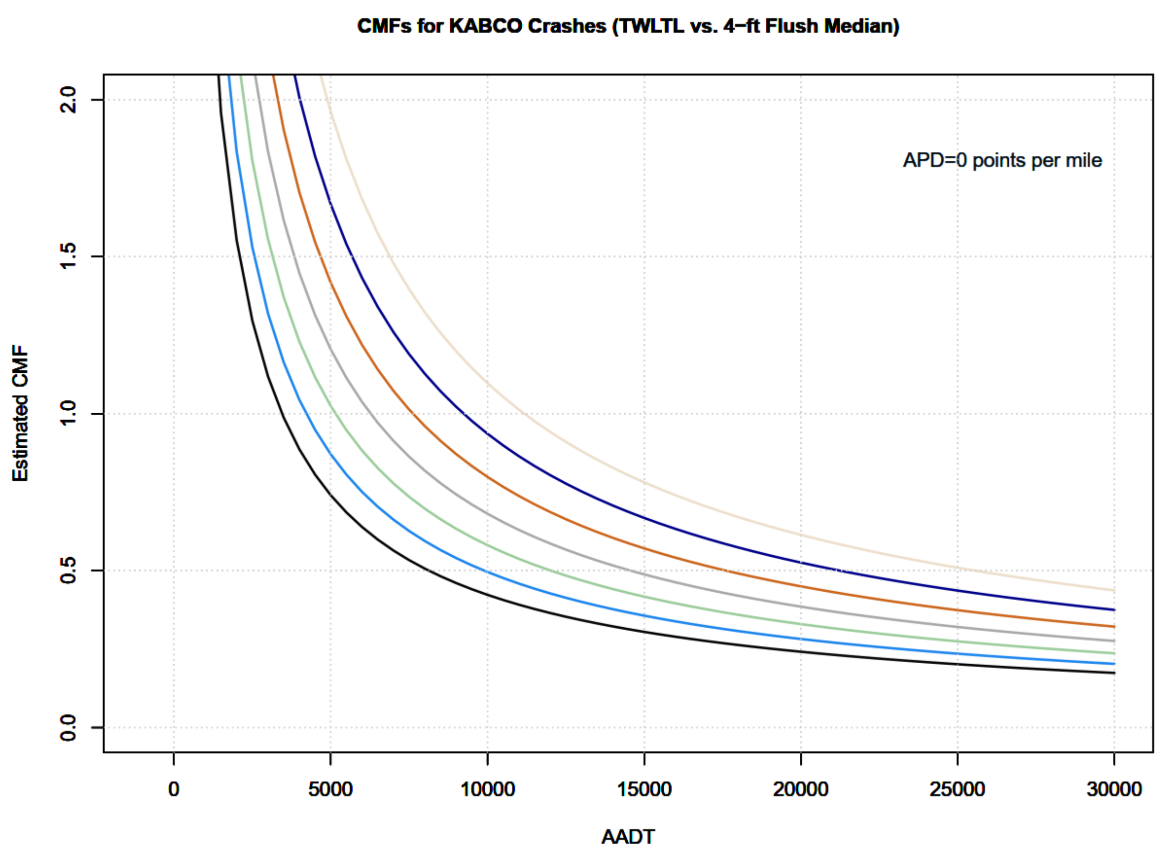
5000
10000
15000
AADT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APD=0 points per mile
Estimated CMF
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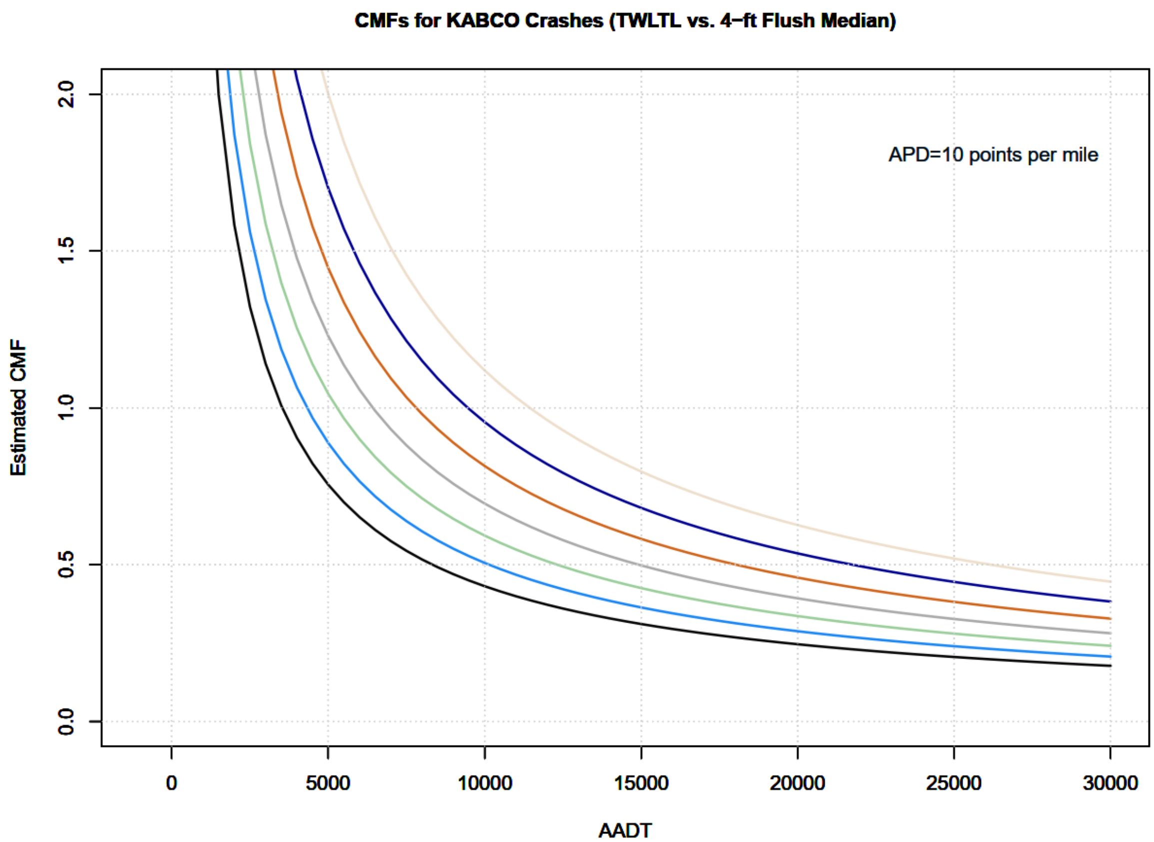
1.0
1.5
2.0
0
5000
10000
15000
20000
25000
30000
AADT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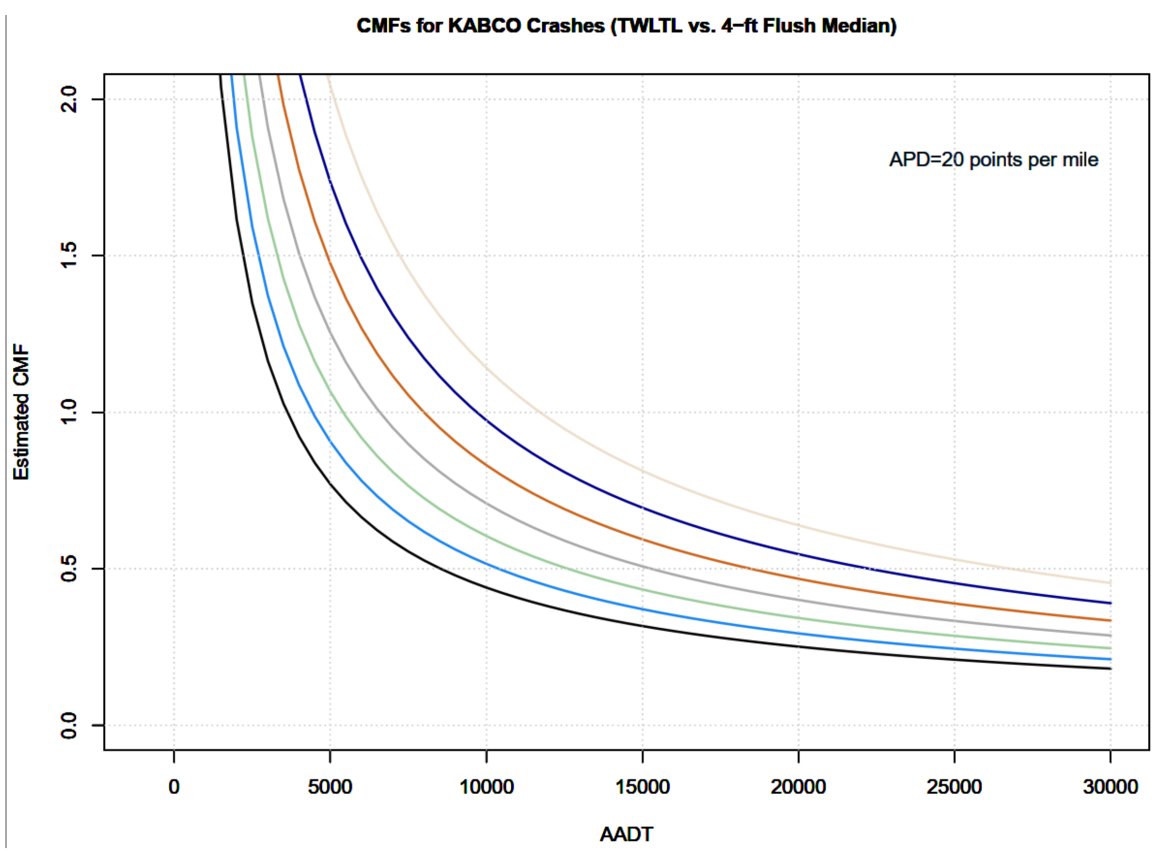
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25000
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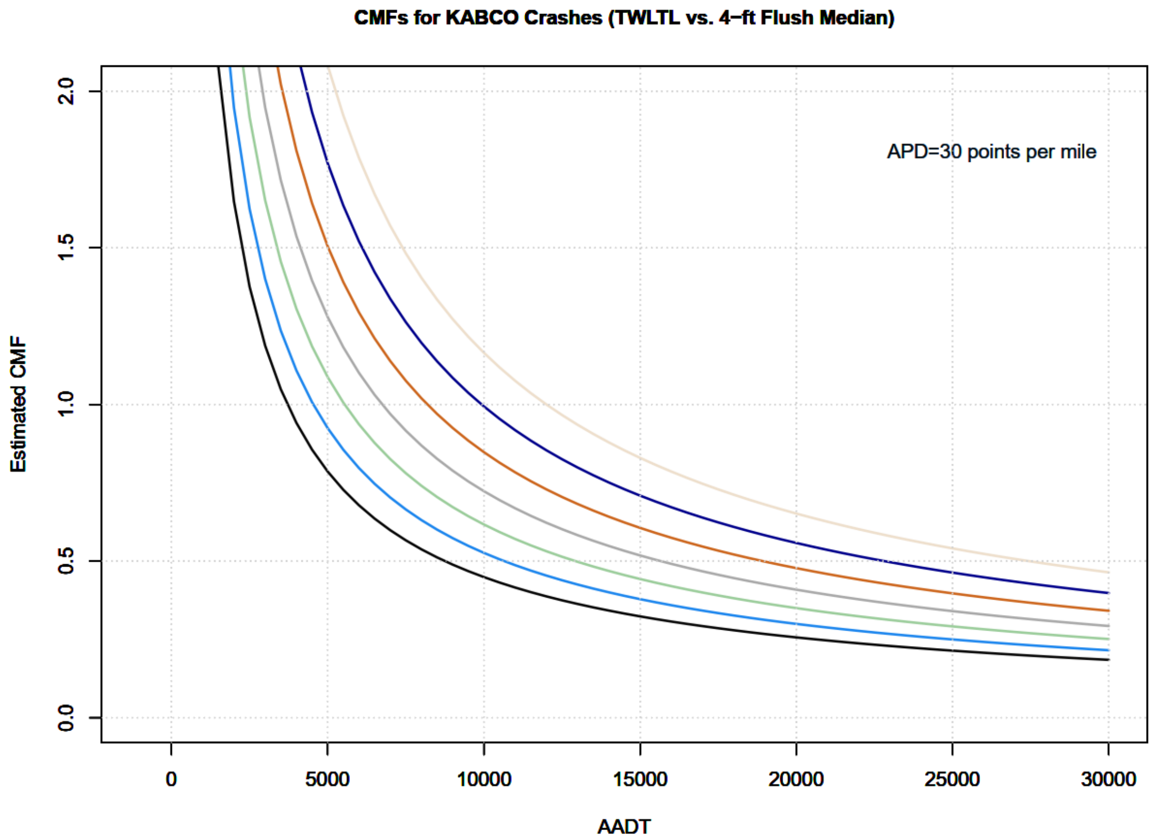
CMFs for KABCO Crashes (TWLTL vs. 4−ft Flush Median)
APD=30 points per mile
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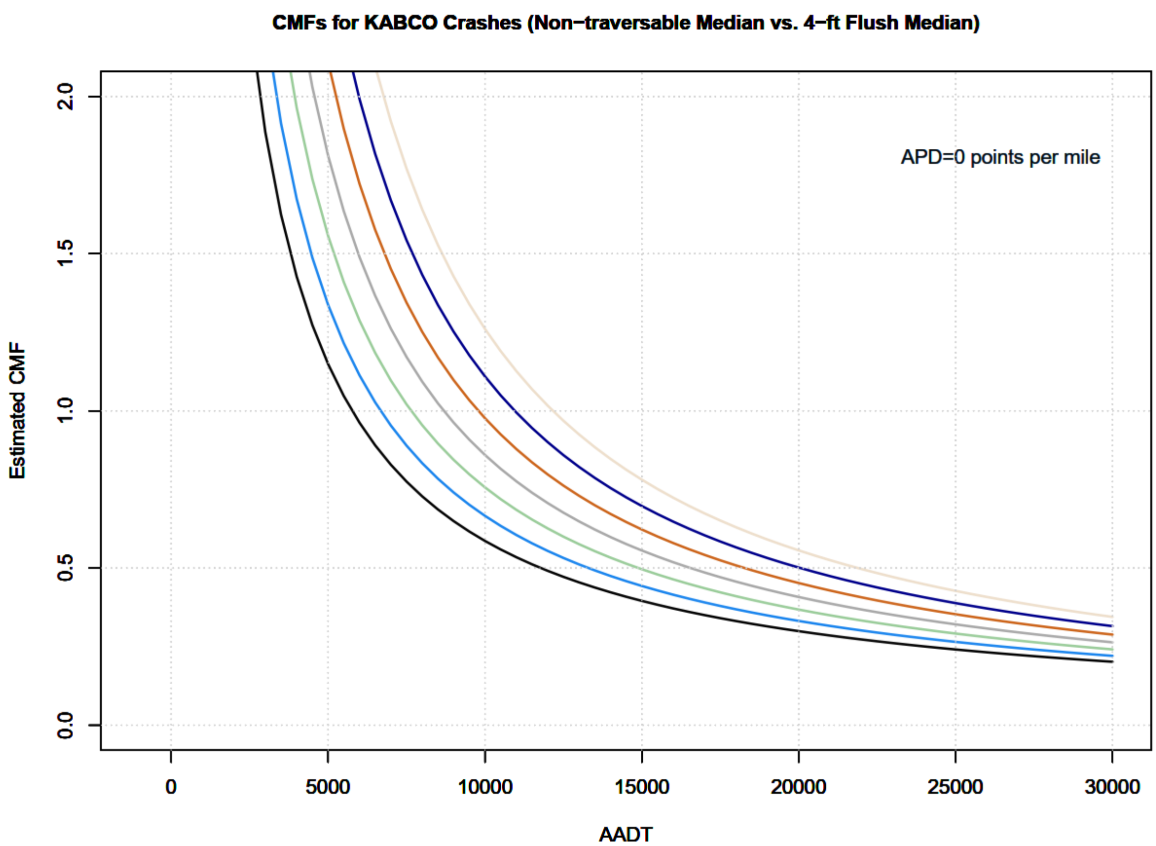
20000
25000
30000


CMFs for KABCO Crashes (Non−traversable Median vs. 4−ft Flush Median)
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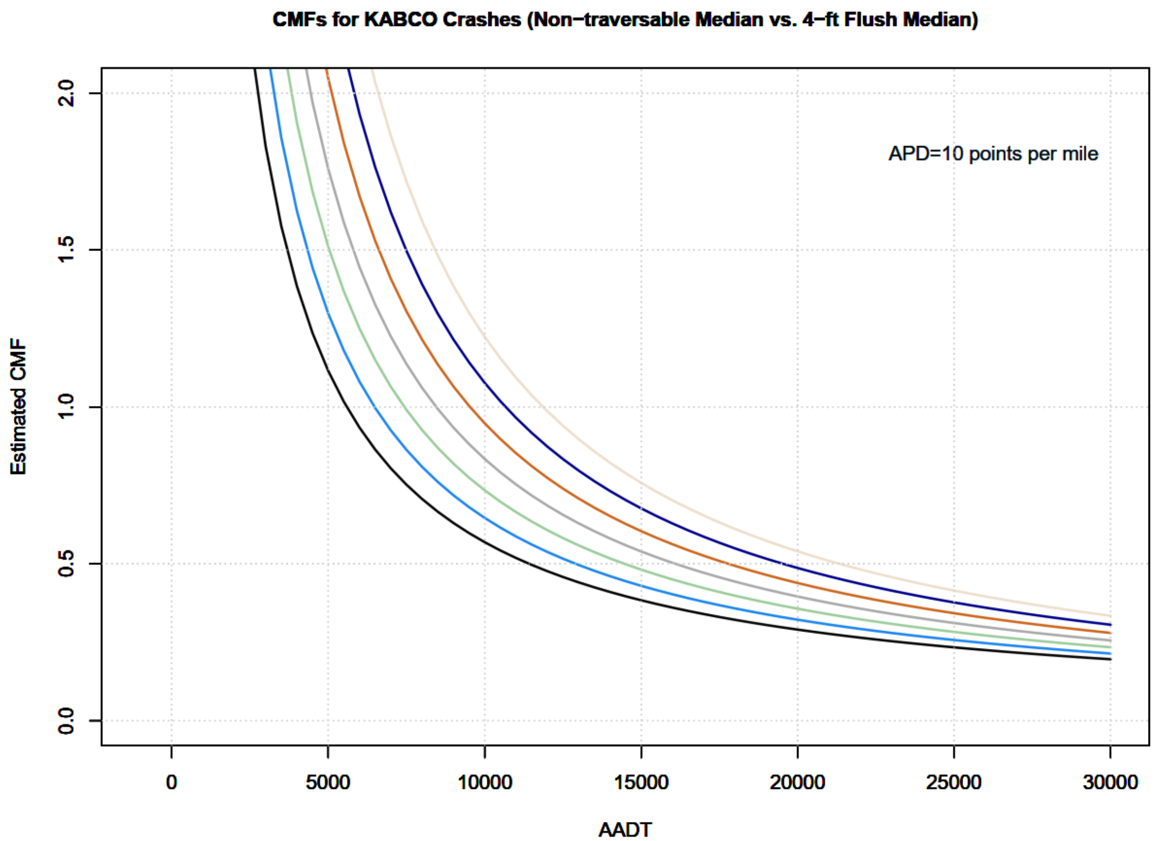
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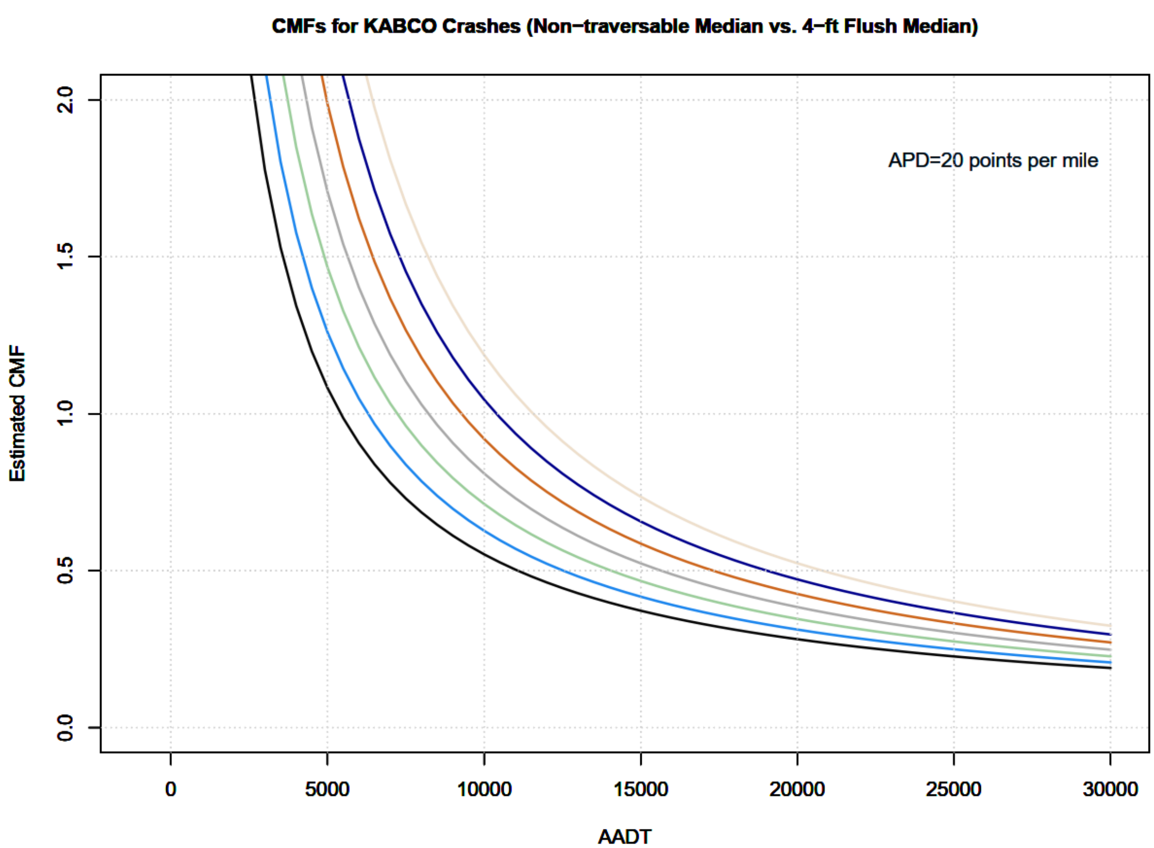
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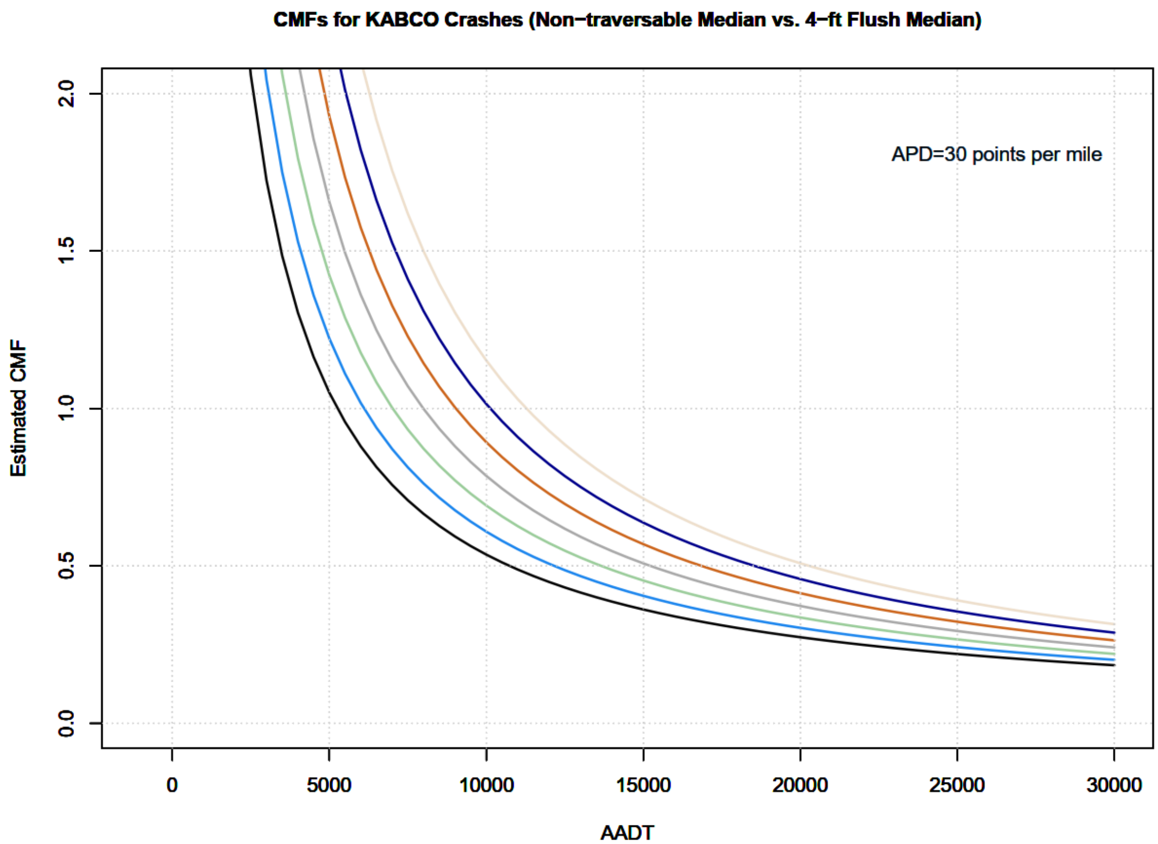
AADT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2.0
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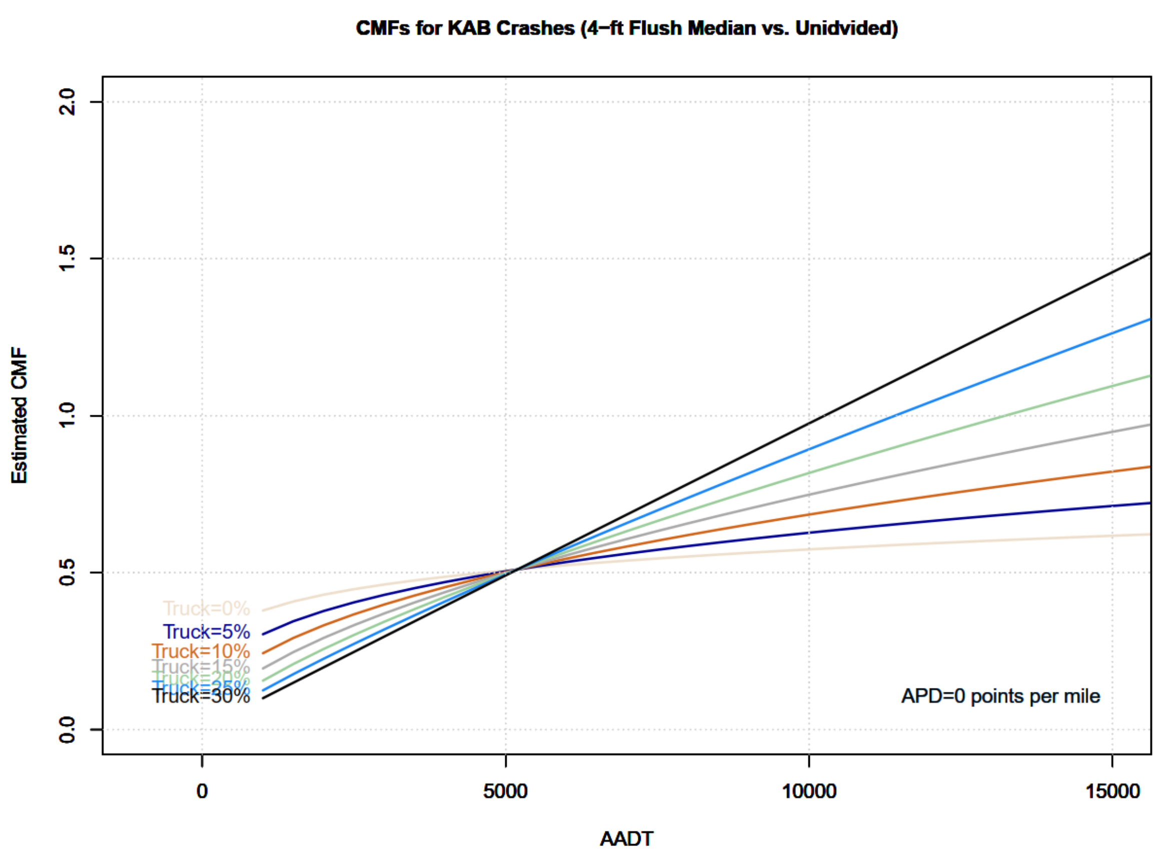
25000
30000
AADT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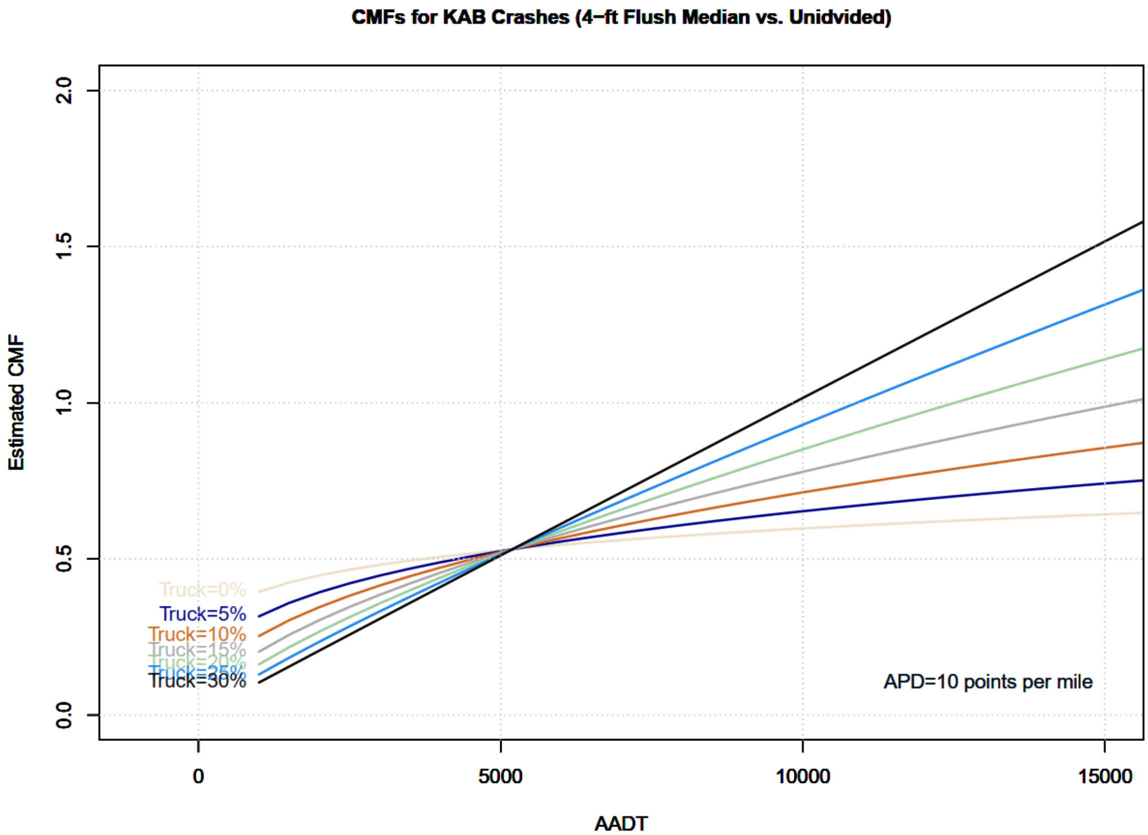
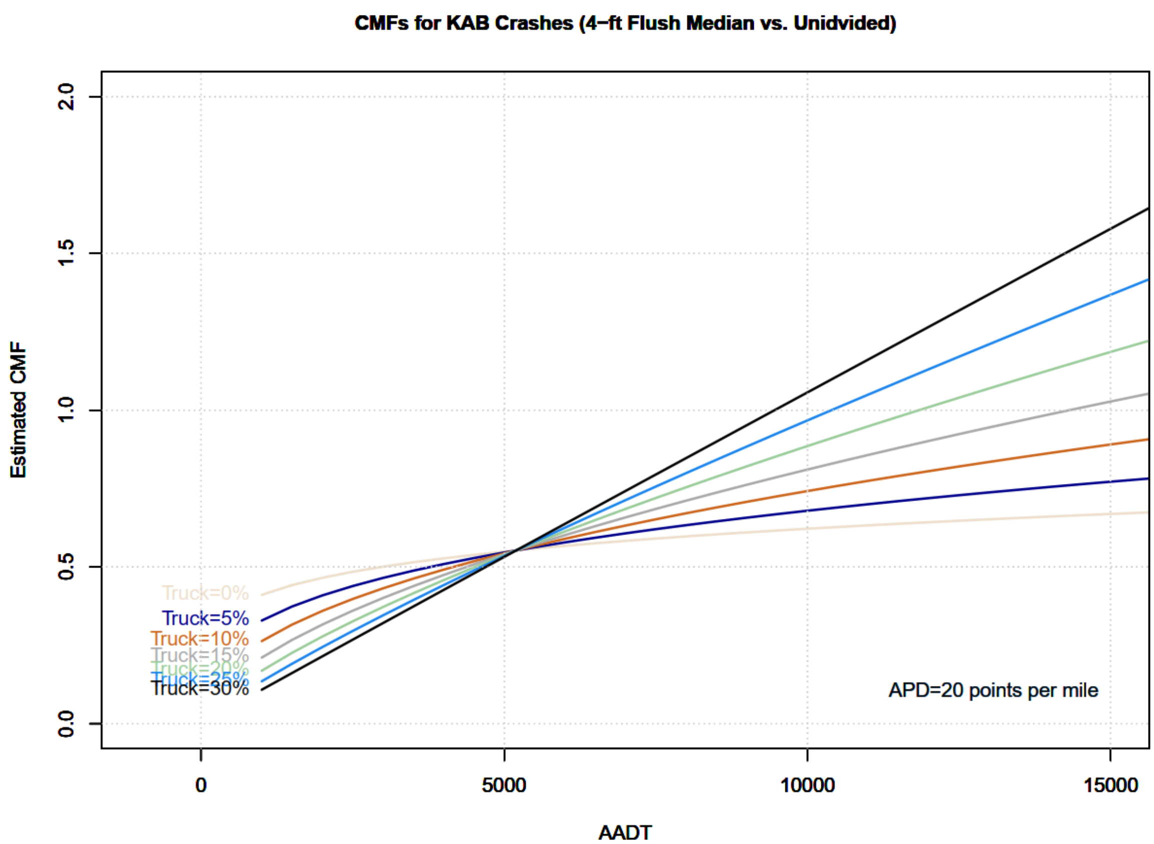
Truck=5%
Truck=10%
Truck=15%
Truck=30%
APD=0 points per mile
Estimated CMF
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000
AADT


CMFs for KAB Crashes (4−ft Flush Median vs. Unidvided)
Estimated CMF
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000
AADT
Truck=0%
Truck=5%
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=10 points per mile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Estimated CMF
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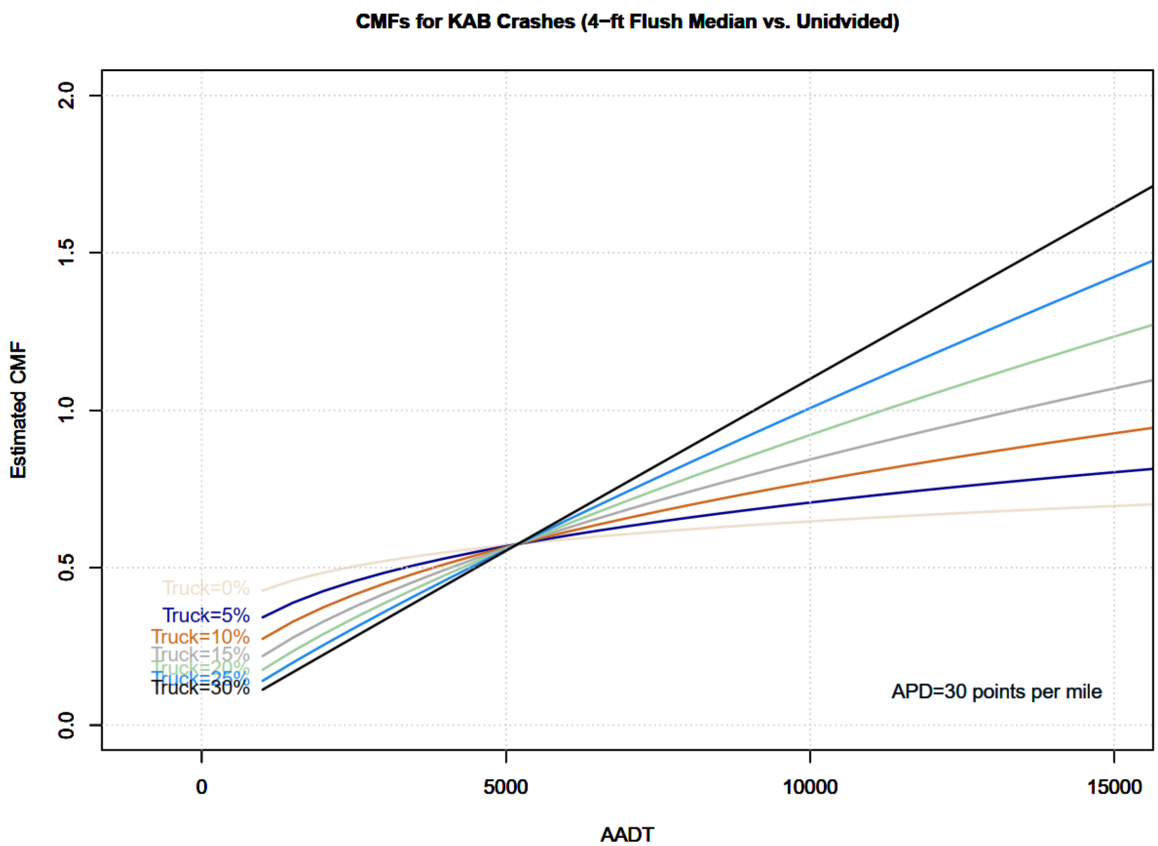
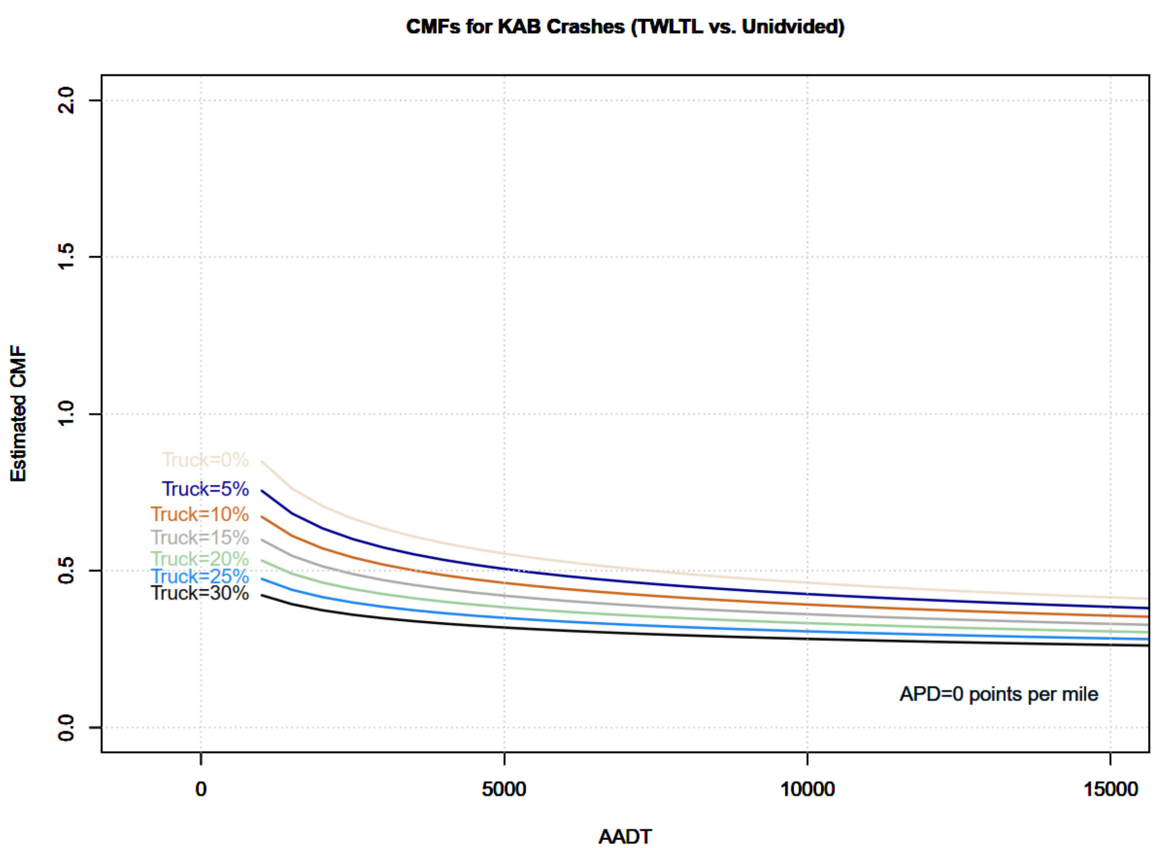
0.5
1.0
1.5
2.0
0
5000
10000
15000
AADT
Truck=0%
Truck=5%
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=20 points per mile


CMFs for KAB Crashes (4−ft Flush Median vs. Unidvided)
Estimated CMF
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000
AADT
Truck=0%
Truck=5%
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=30 points per mile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Estimated CMF
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0.5
1.0
1.5
2.0
0
5000
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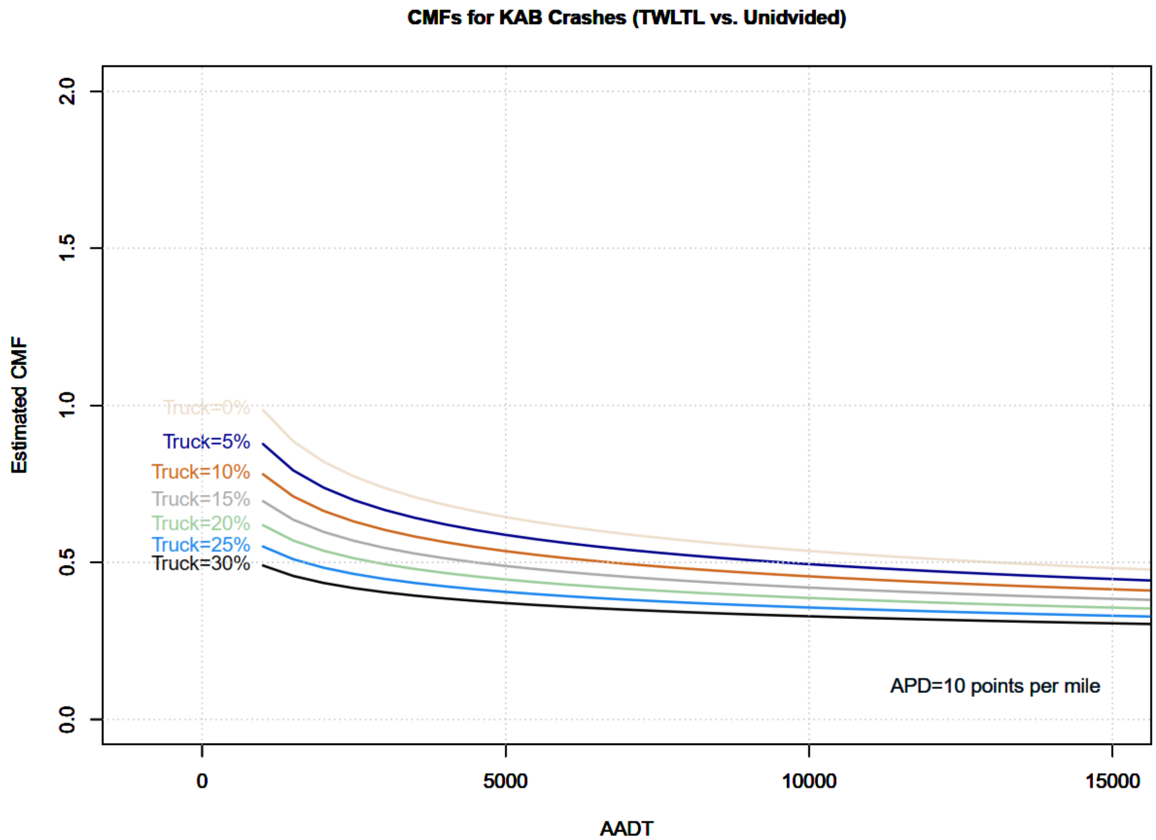
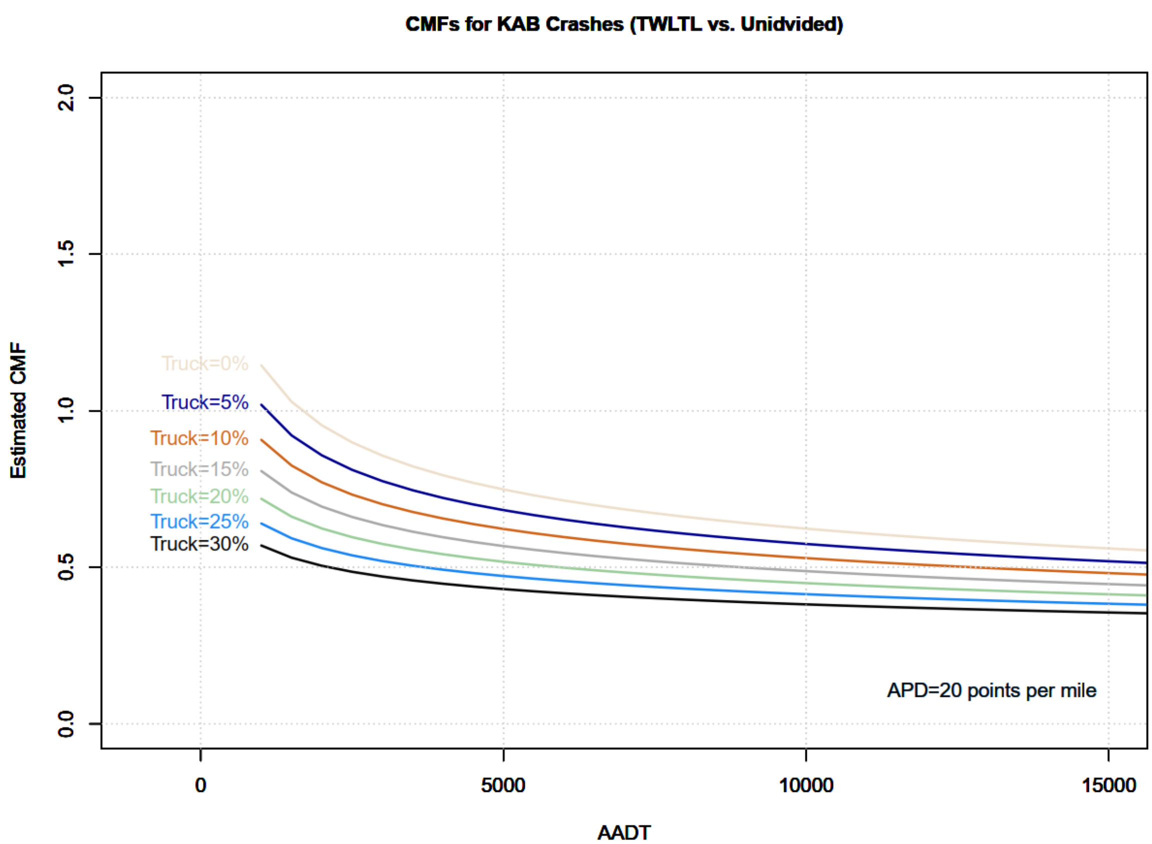
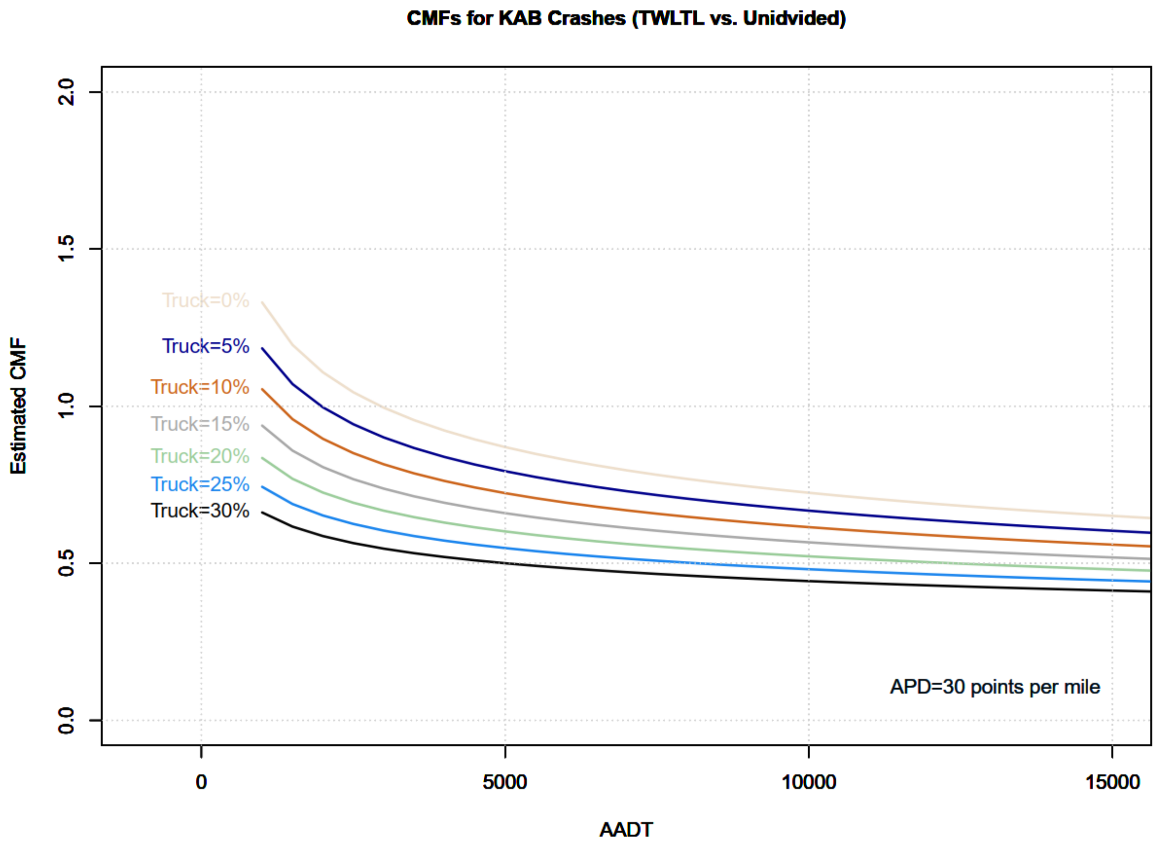
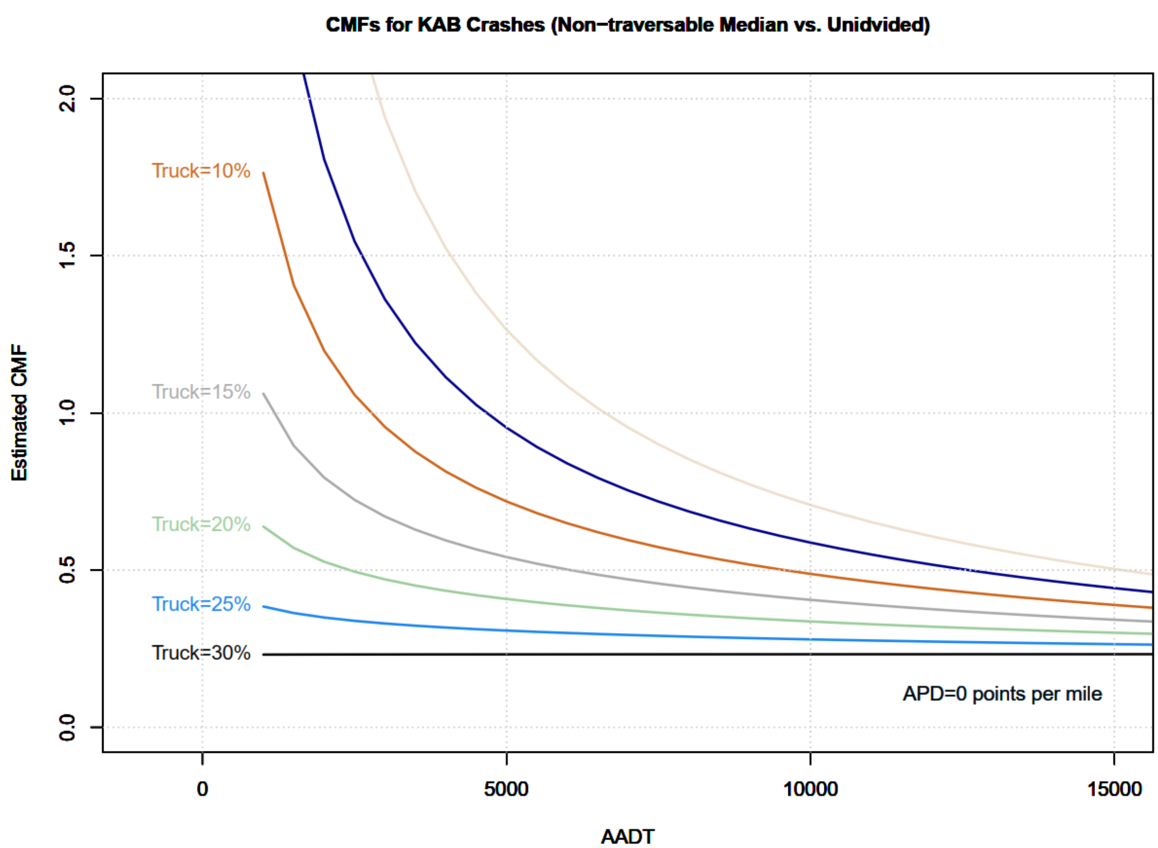
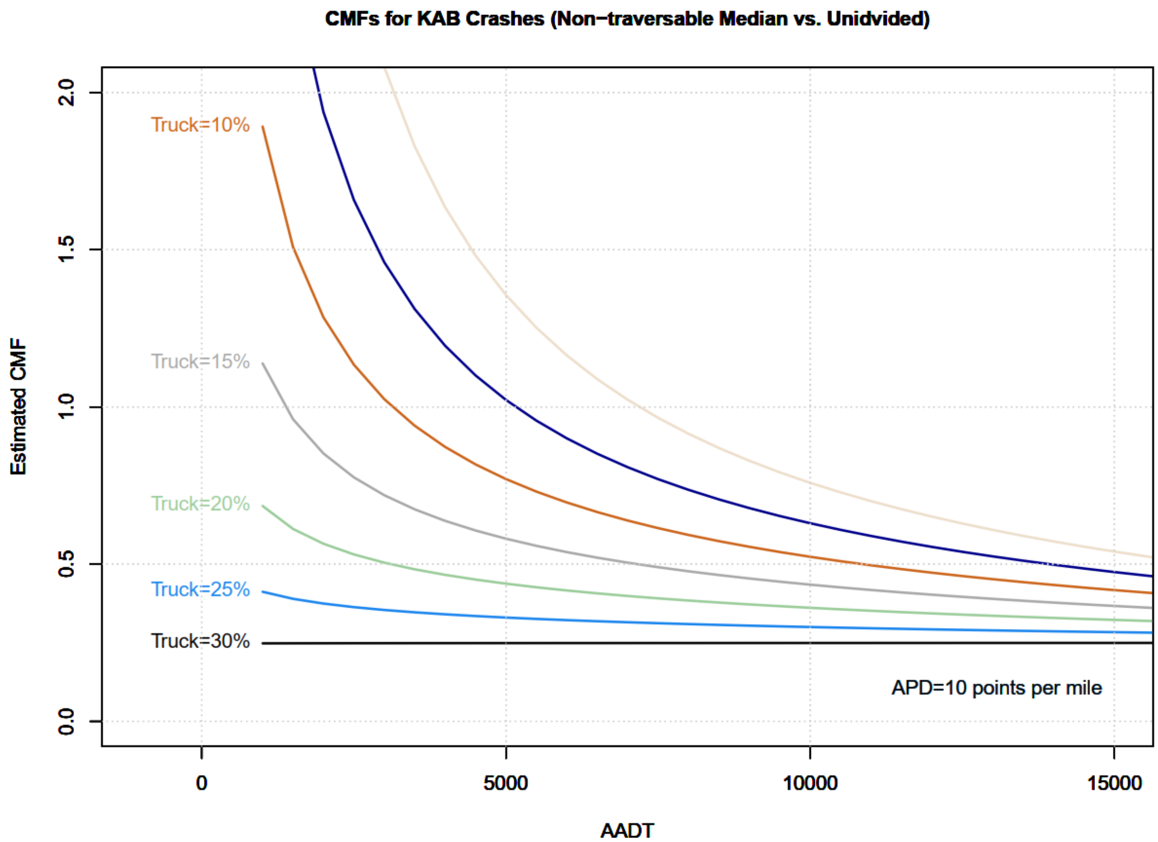
Truck=30%
APD=0 points per mile

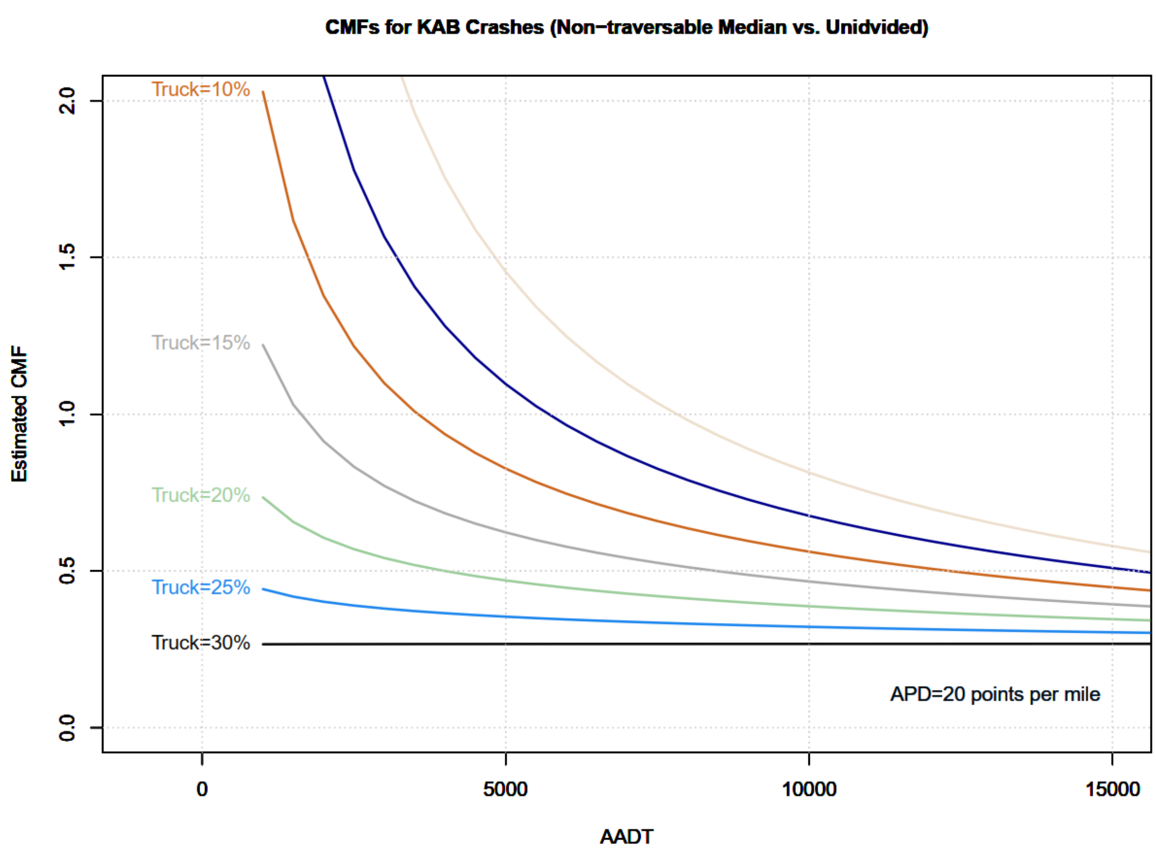

CMFs for KAB Crashes (TWLTL vs. Unidvided)
Estimated CMF
0.0
0.5
1.0
1.5
2.0
Truck=0%
Truck=5%
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=10 points per mile
0
5000
10000
15000
AADT


CMFs for KAB Crashes (TWLTL vs. Unidvided)
Estimated CMF
0.0
0.5
1.0
1.5
2.0
Truck=0%
Truck=5%
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=20 points per mile
0
5000
10000
15000
AADT

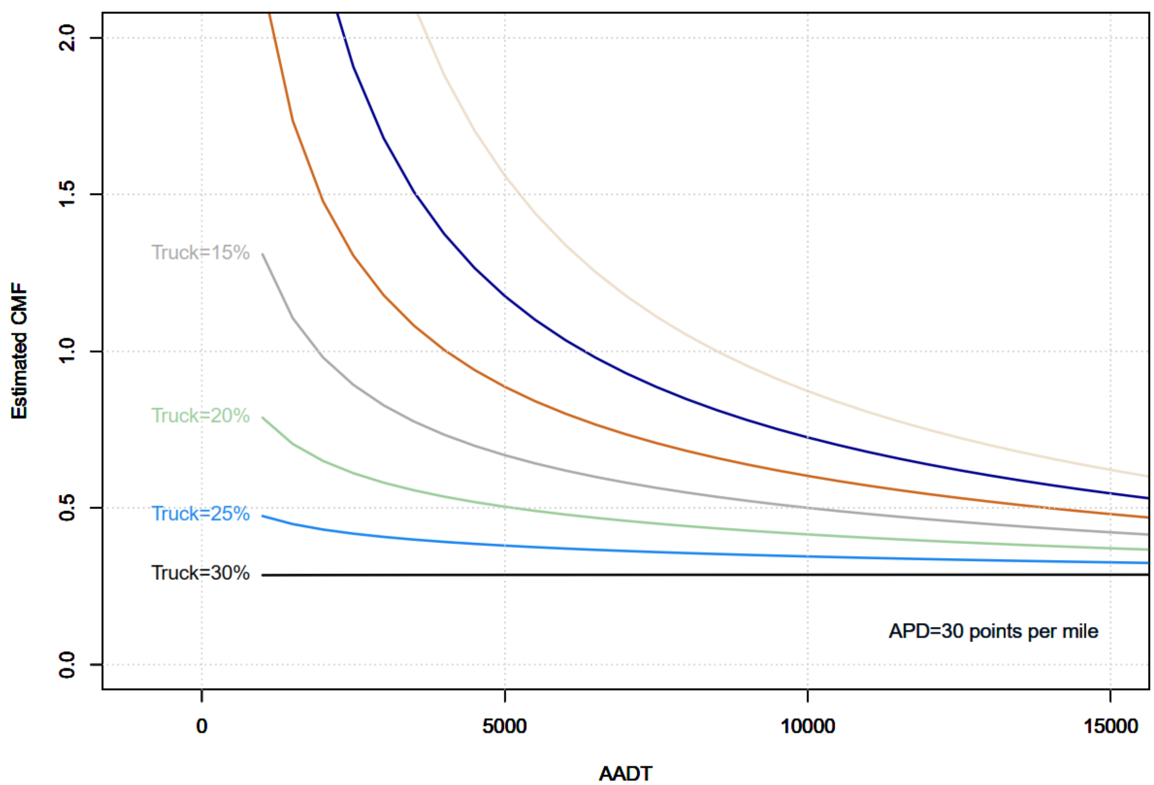

CMFs for KAB Crashes (TWLTL vs. Unidvided)
Estimated CMF
AADT
Truck=0%
Truck=5%
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=30 points per mile
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000


CMFs for KAB Crashes (Non−traversable Median vs. Unidvided)
Estimated CMF
AADT
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=0 points per mile
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000

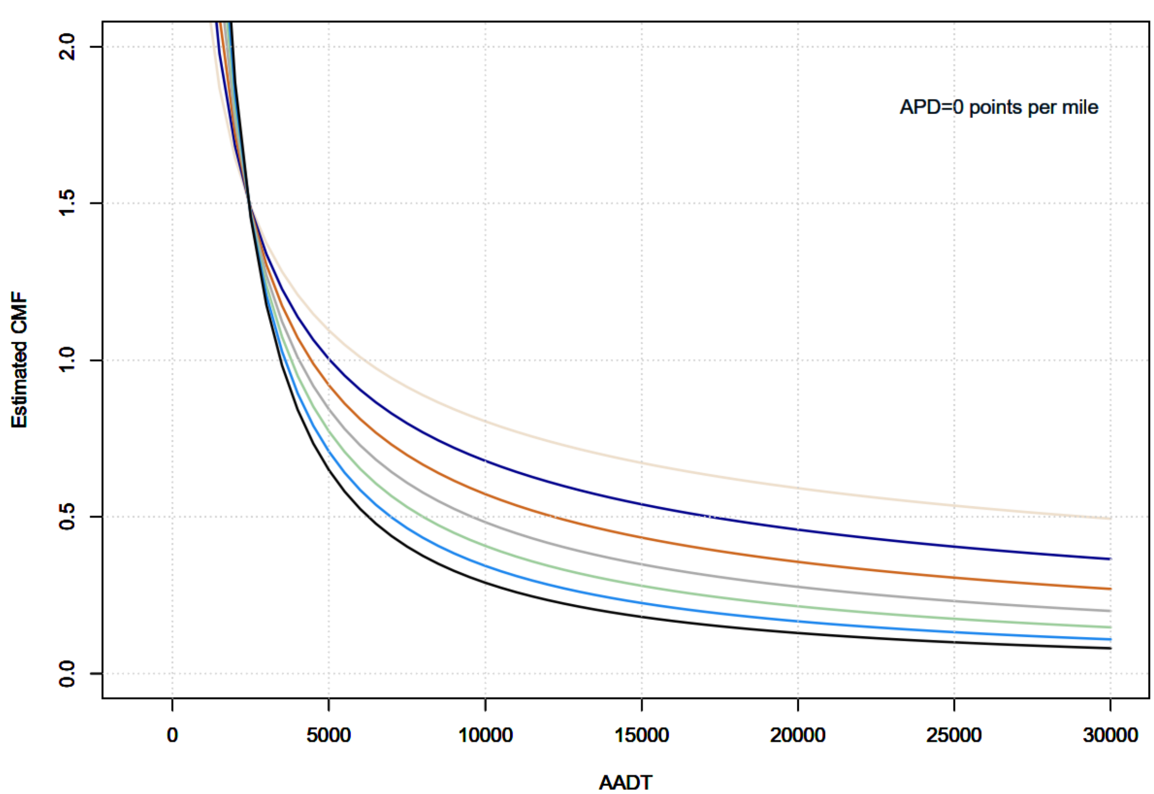

CMFs for KAB Crashes (Non−traversable Median vs. Unidvided)
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=10 points per mile
Estimated CMF
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000
AADT


CMFs for KAB Crashes (Non−traversable Median vs. Unidvided)
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=20 points per mile
Estimated CMF
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000
AADT

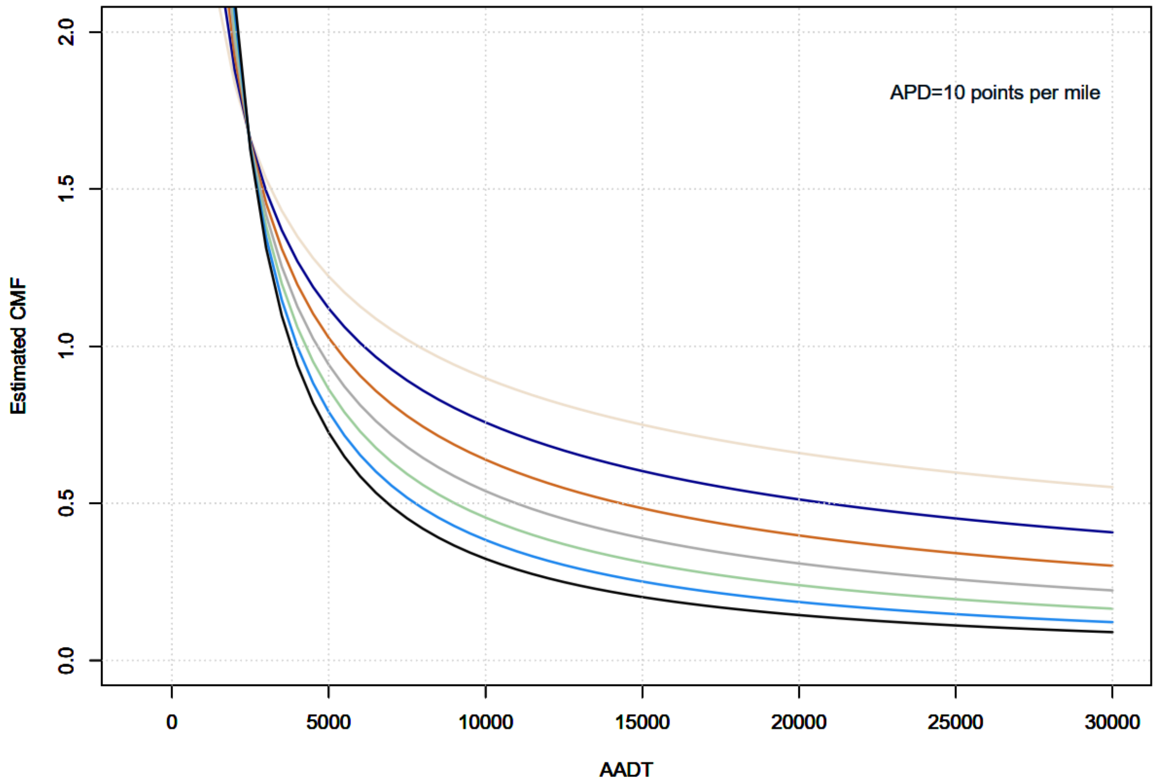
CMFs for KAB Crashes (Non−traversable Median vs. Unidvided)



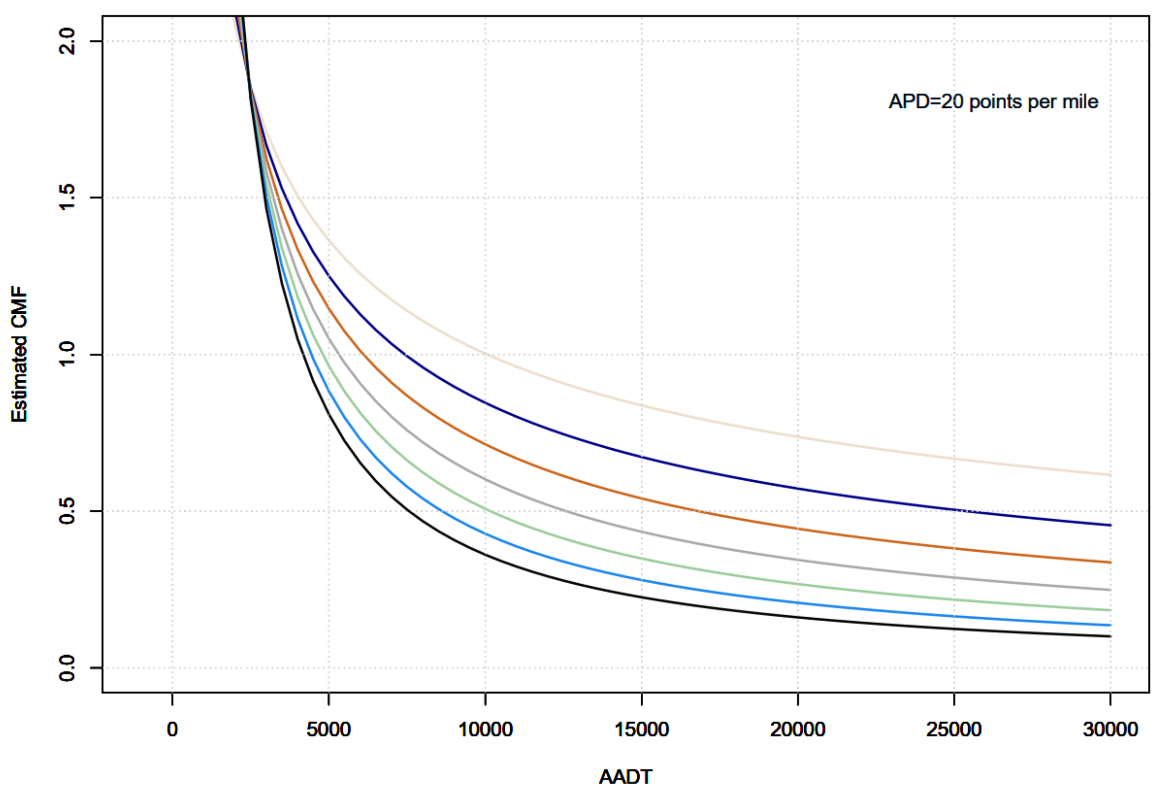
CMFs for KAB Crashes (TWLTL vs. 4−ft Flush Median)



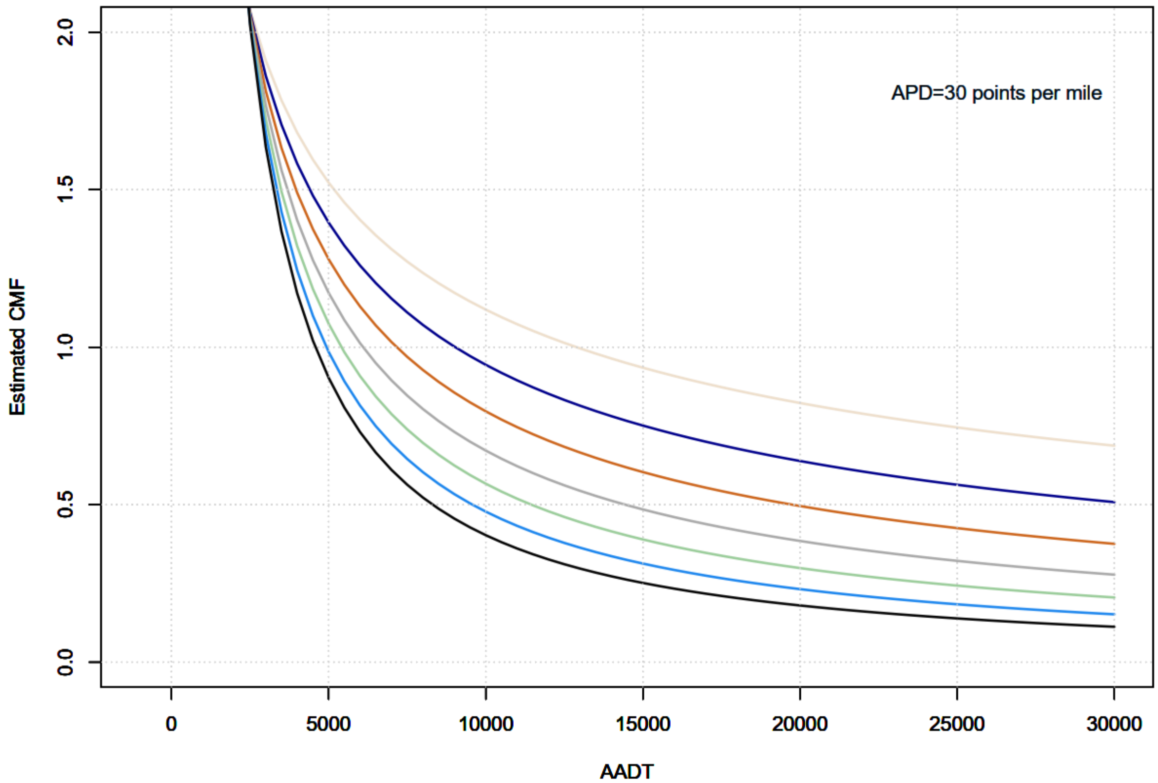
CMFs for KAB Crashes (TWLTL vs. 4−ft Flush Median)



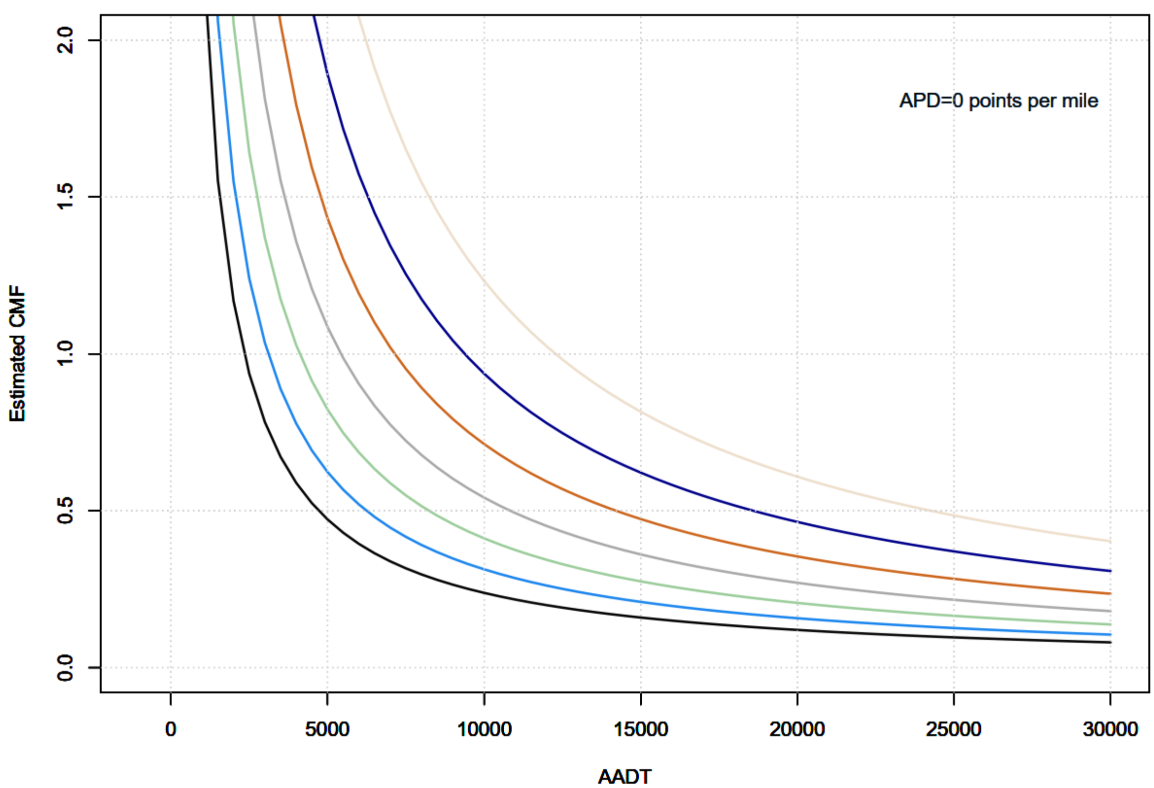
CMFs for KAB Crashes (TWLTL vs. 4−ft Flush Median)

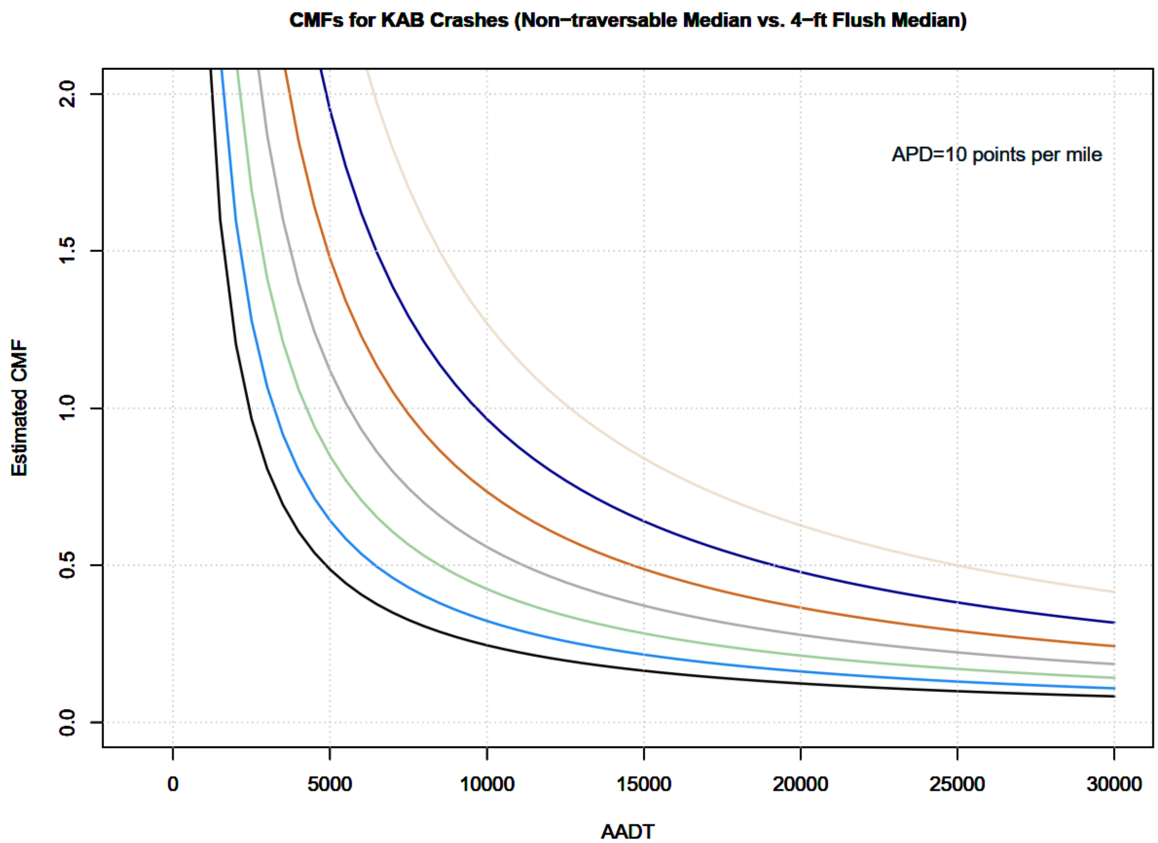


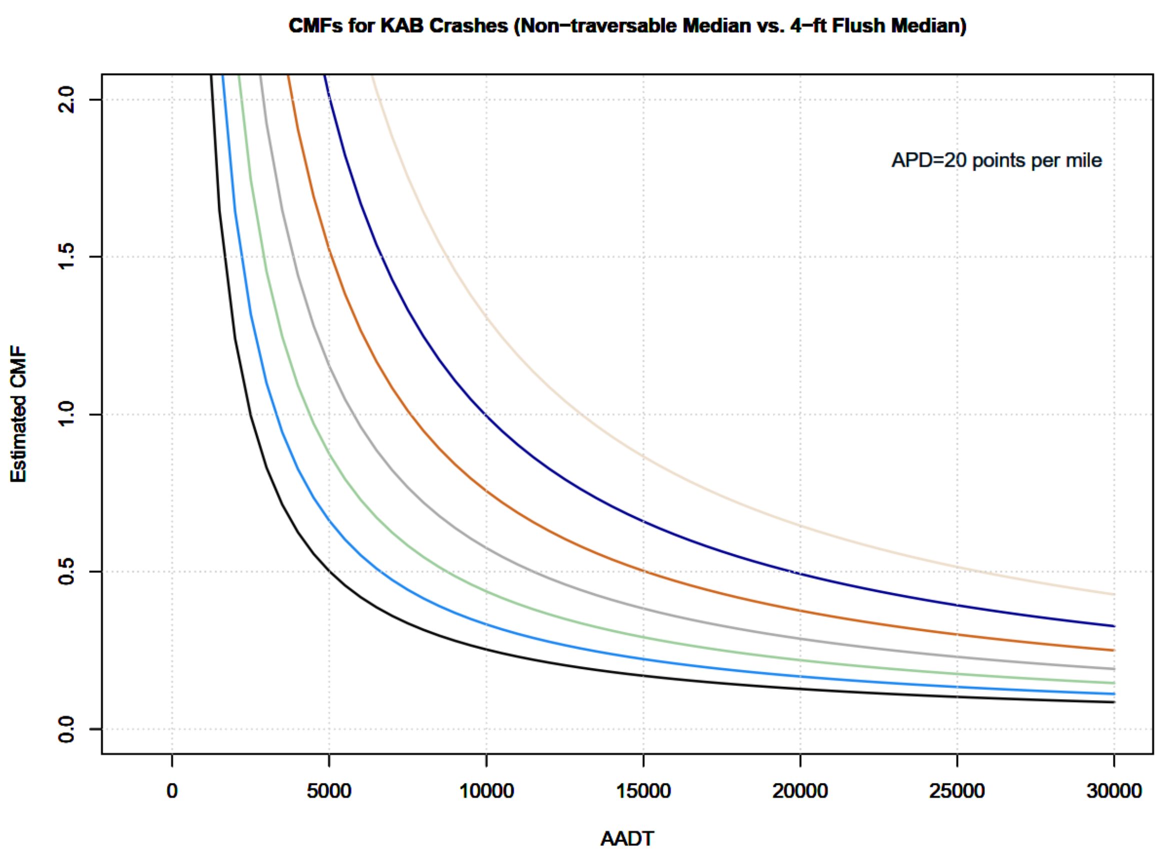
CMFs for KAB Crashes (TWLTL vs. 4−ft Flush Median)



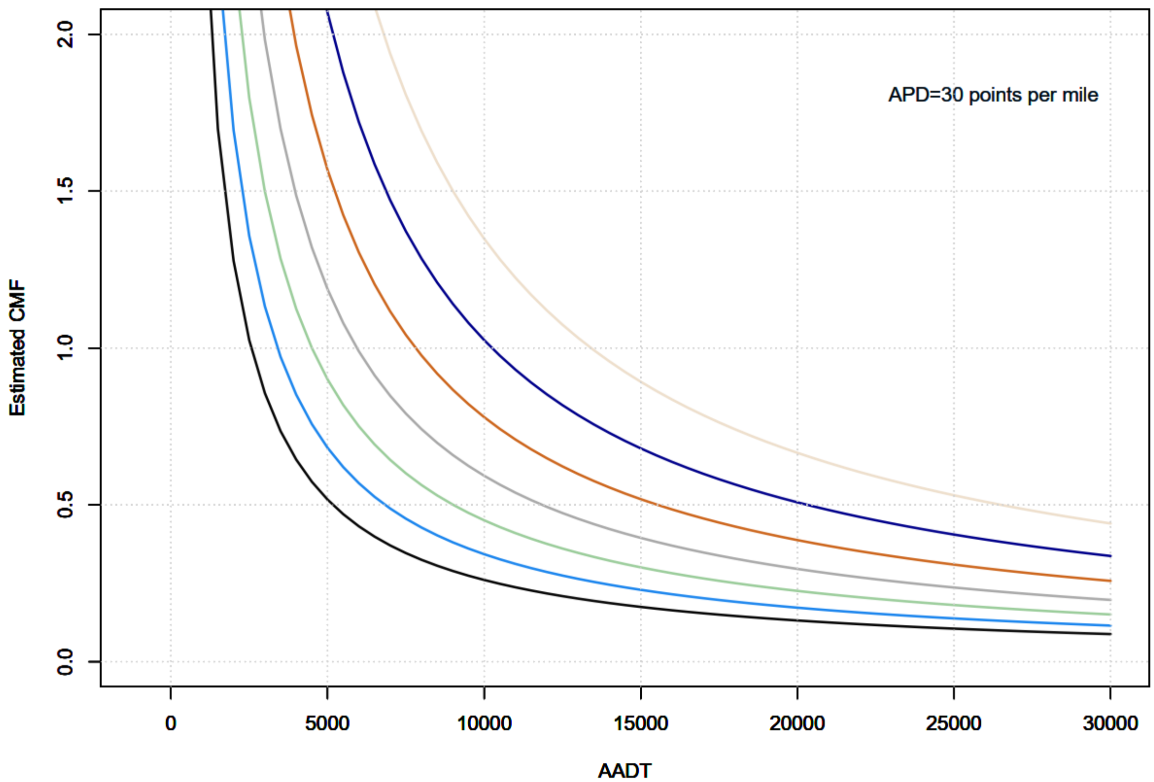
CMFs for KAB Crashes (Non−traversable Median vs. 4−ft Flush Median)



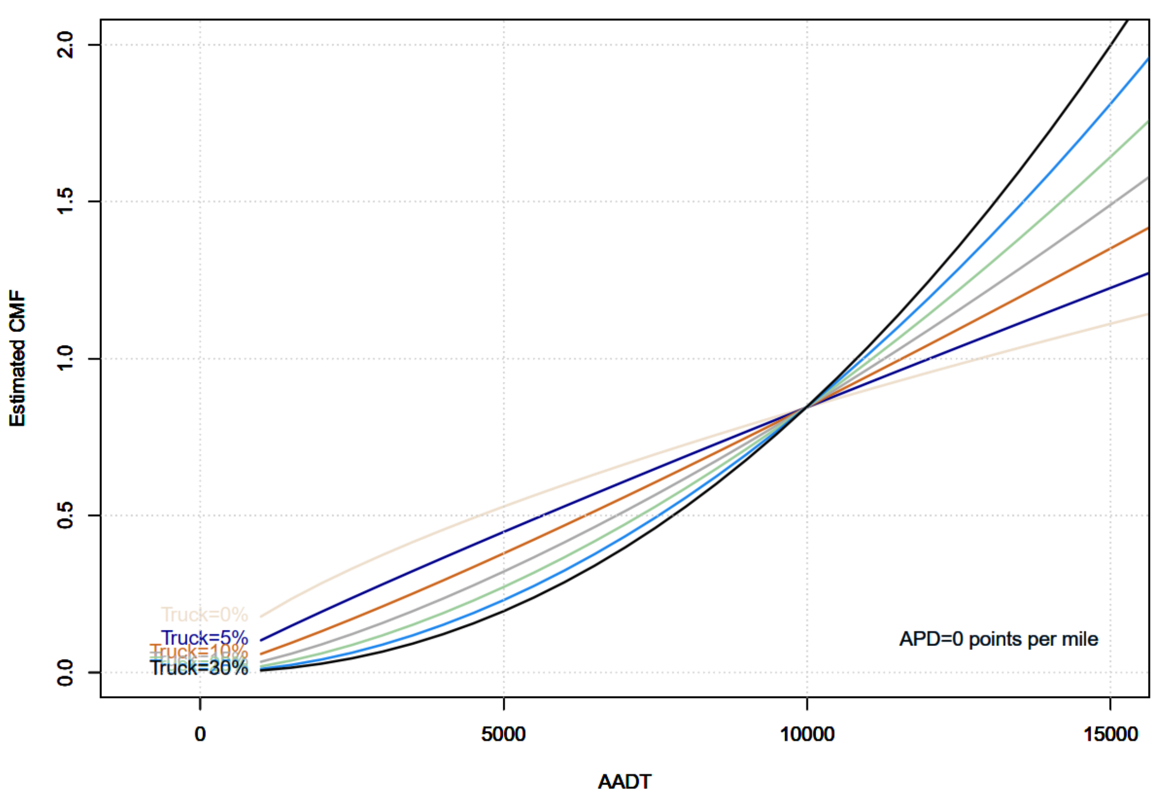

CMFs for KAB Crashes (Non−traversable Median vs. 4−ft Flush Median)
APD=10 points per mile
Estimated CMF
AADT
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000
20000
25000
30000

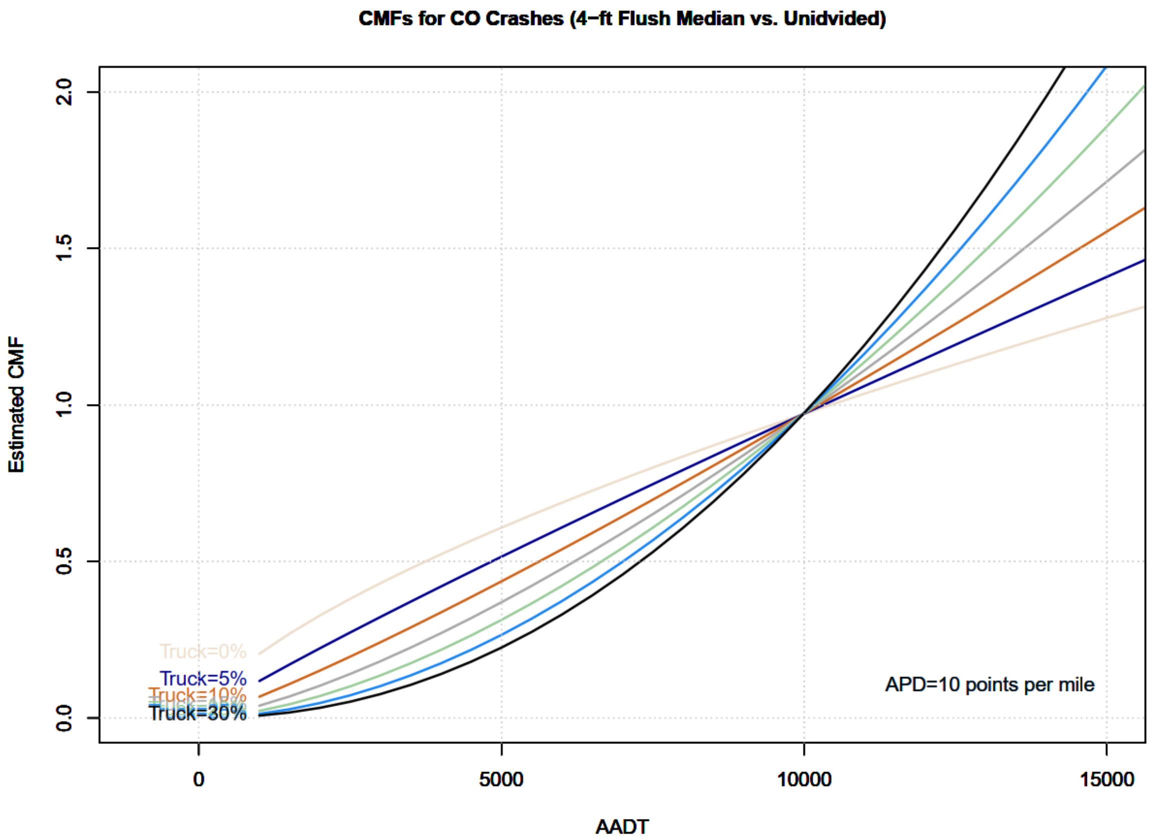

CMFs for KAB Crashes (Non−traversable Median vs. 4−ft Flush Median)
APD=20 points per mile
Estimated CMF
AADT
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000
20000
25000
30000

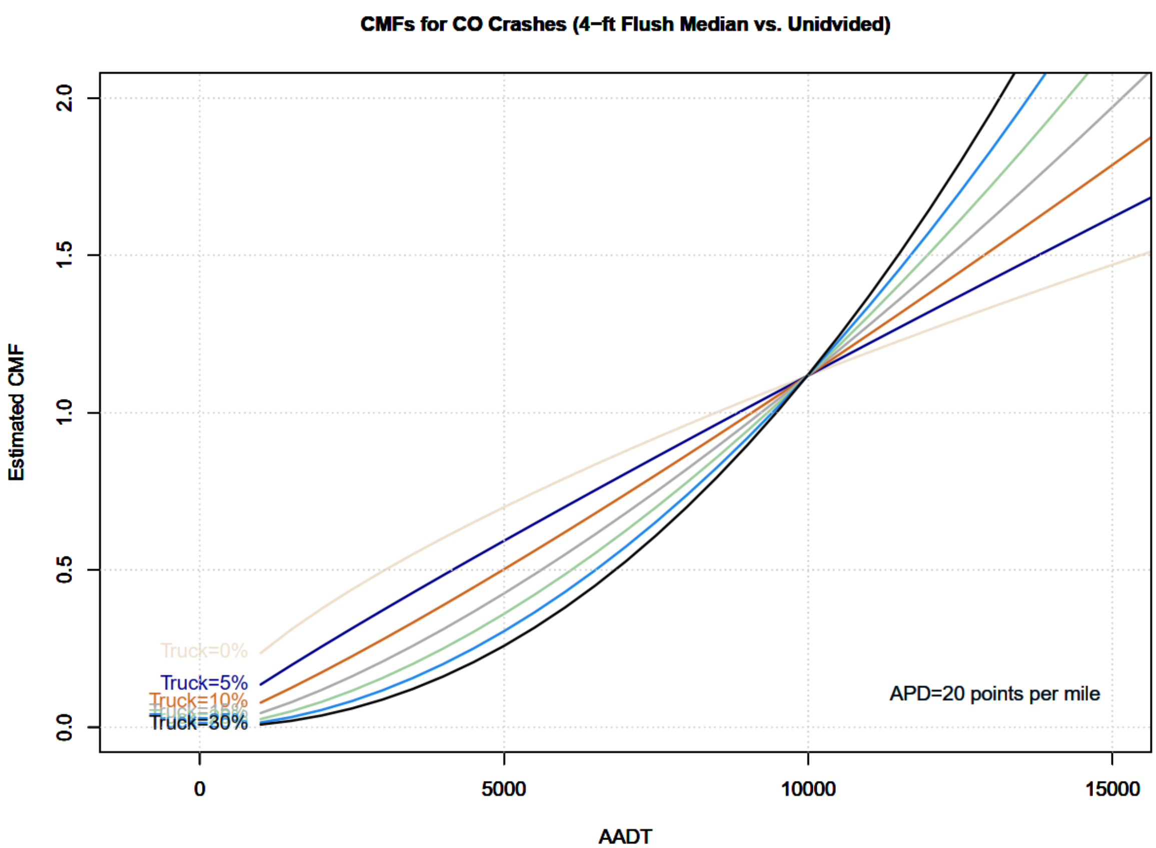
CMFs for KAB Crashes (Non−traversable Median vs. 4−ft Flush Median)



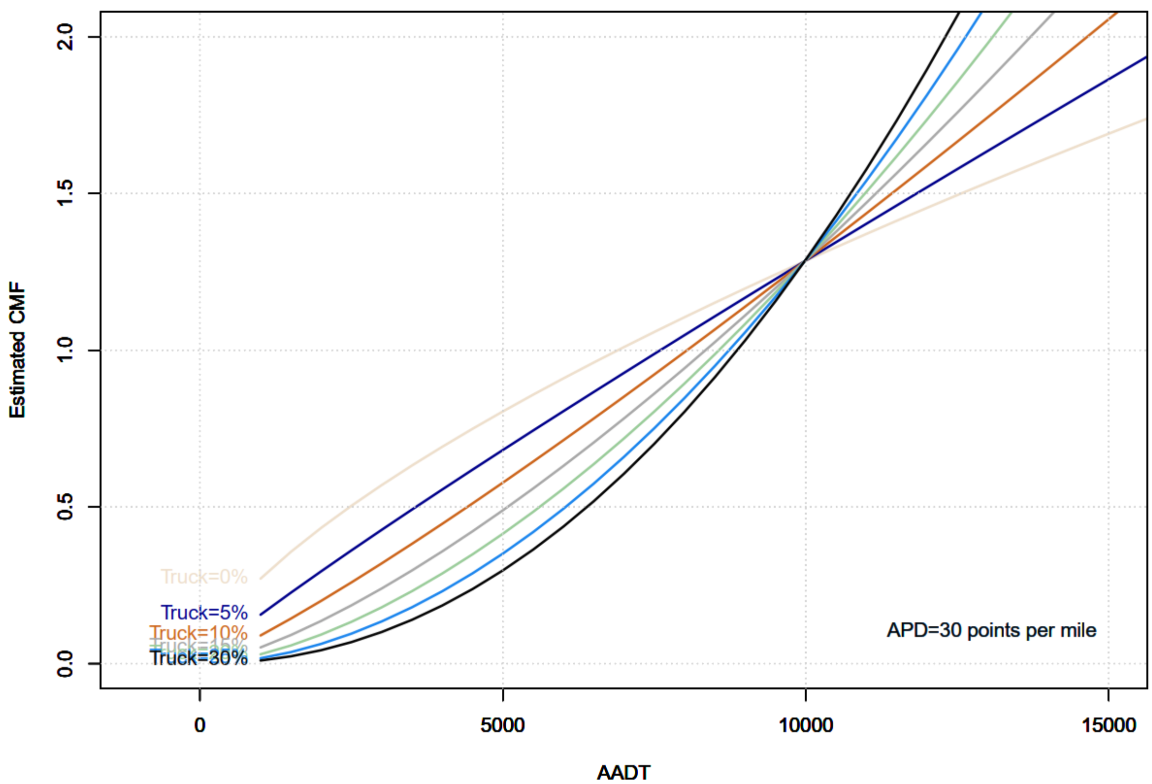
CMFs for CO Crashes (4−ft Flush Median vs. Unidvided)



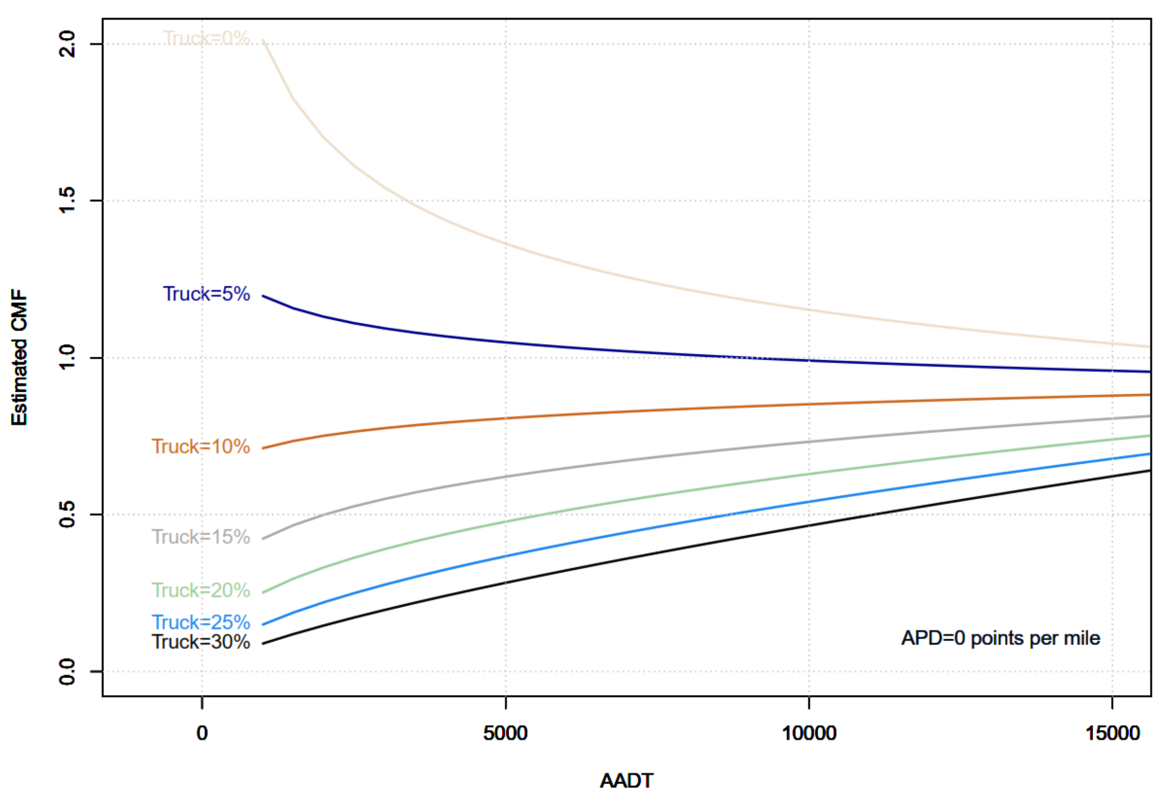

CMFs for CO Crashes (4−ft Flush Median vs. Unidvided)
Estimated CMF
AADT
Truck=0%
Truck=5%
Truck=10%
Truck=30%
APD=10 points per mile
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000

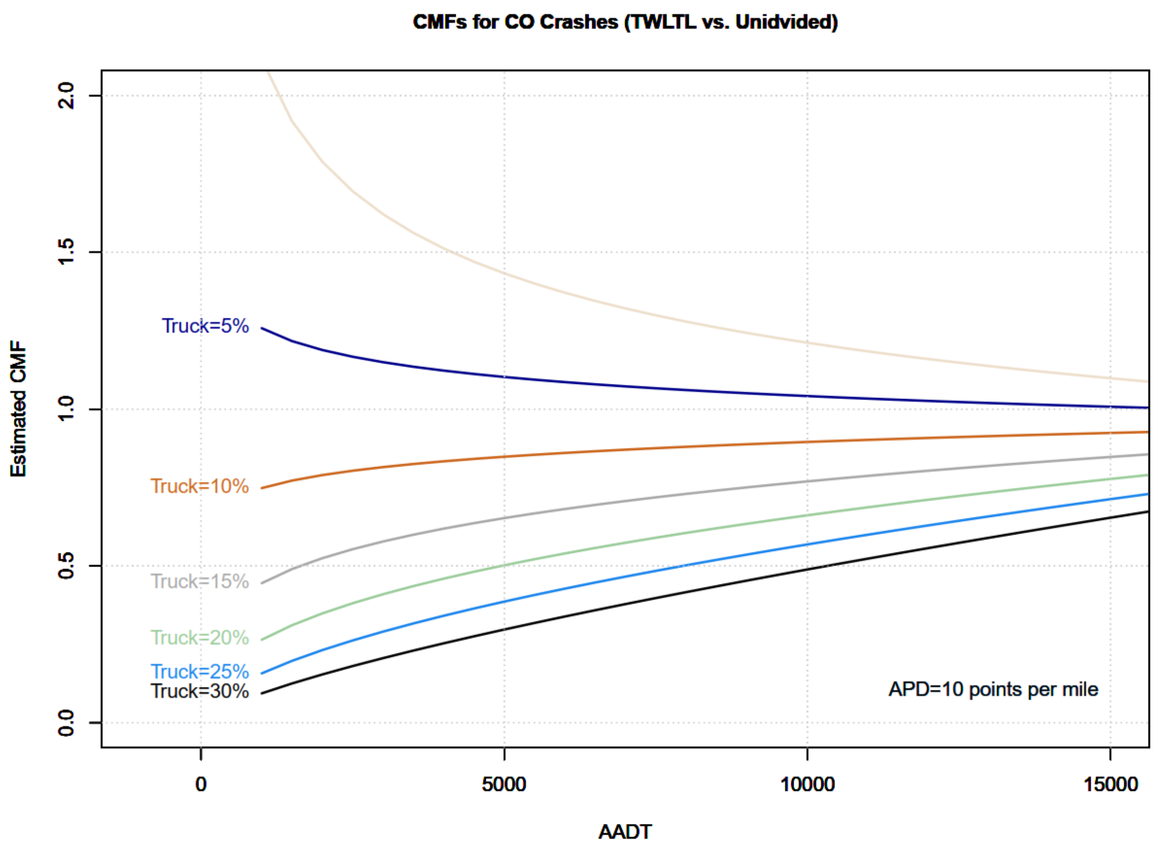

CMFs for CO Crashes (4−ft Flush Median vs. Unidvided)
Estimated CMF
AADT
Truck=0%
Truck=5%
Truck=10%
Truck=30%
APD=20 points per mile
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000

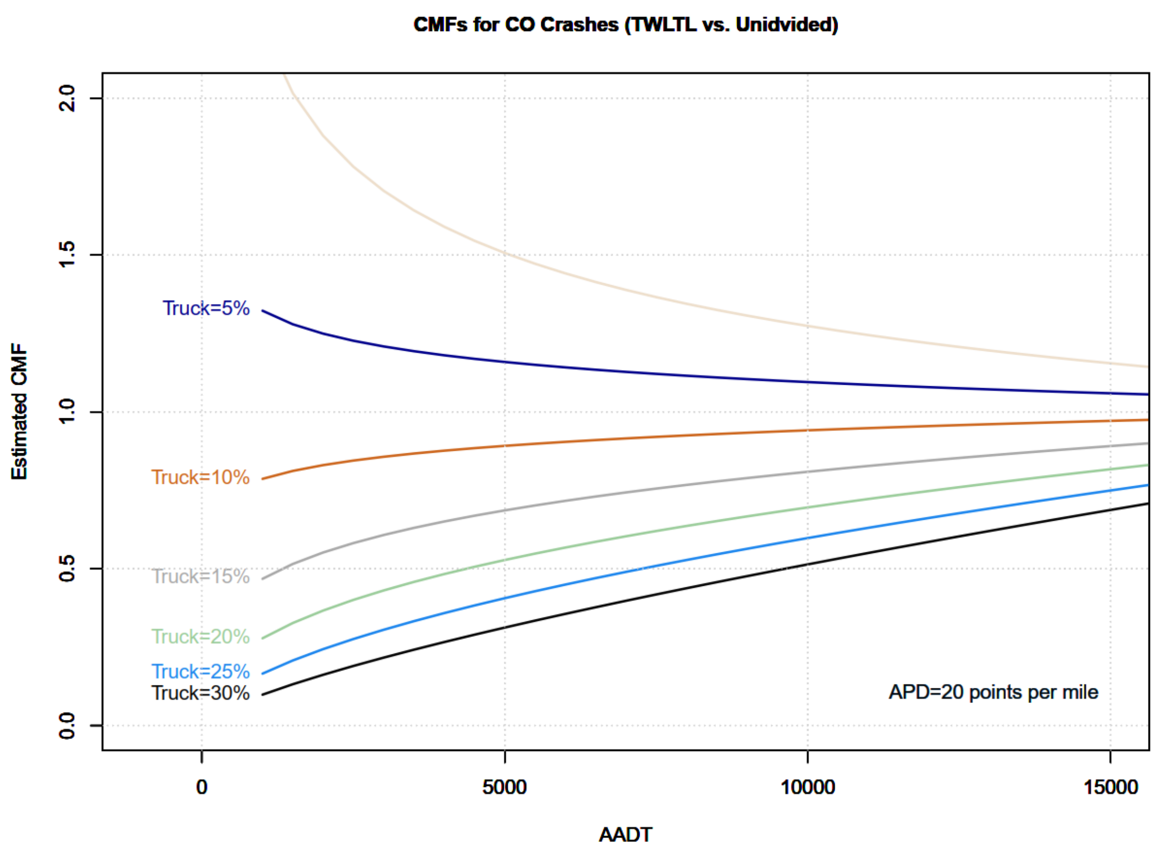
CMFs for CO Crashes (4−ft Flush Median vs. Unidvided)

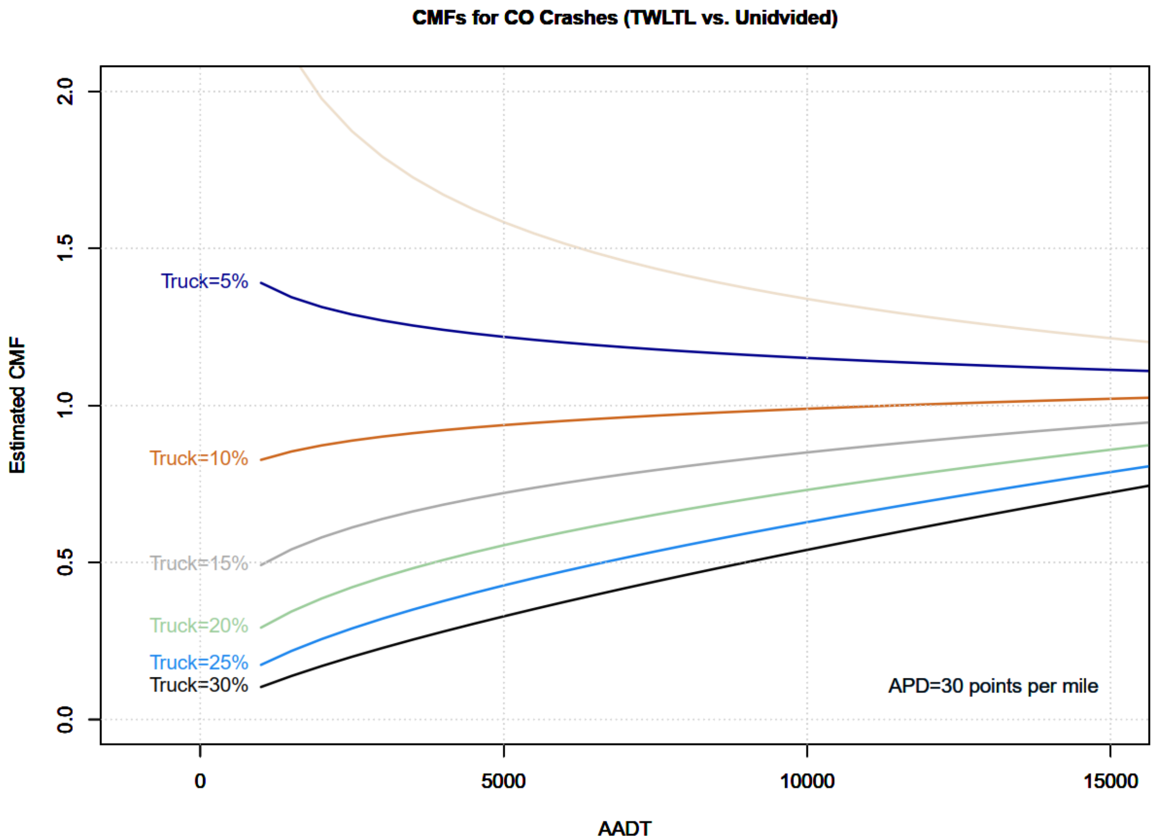


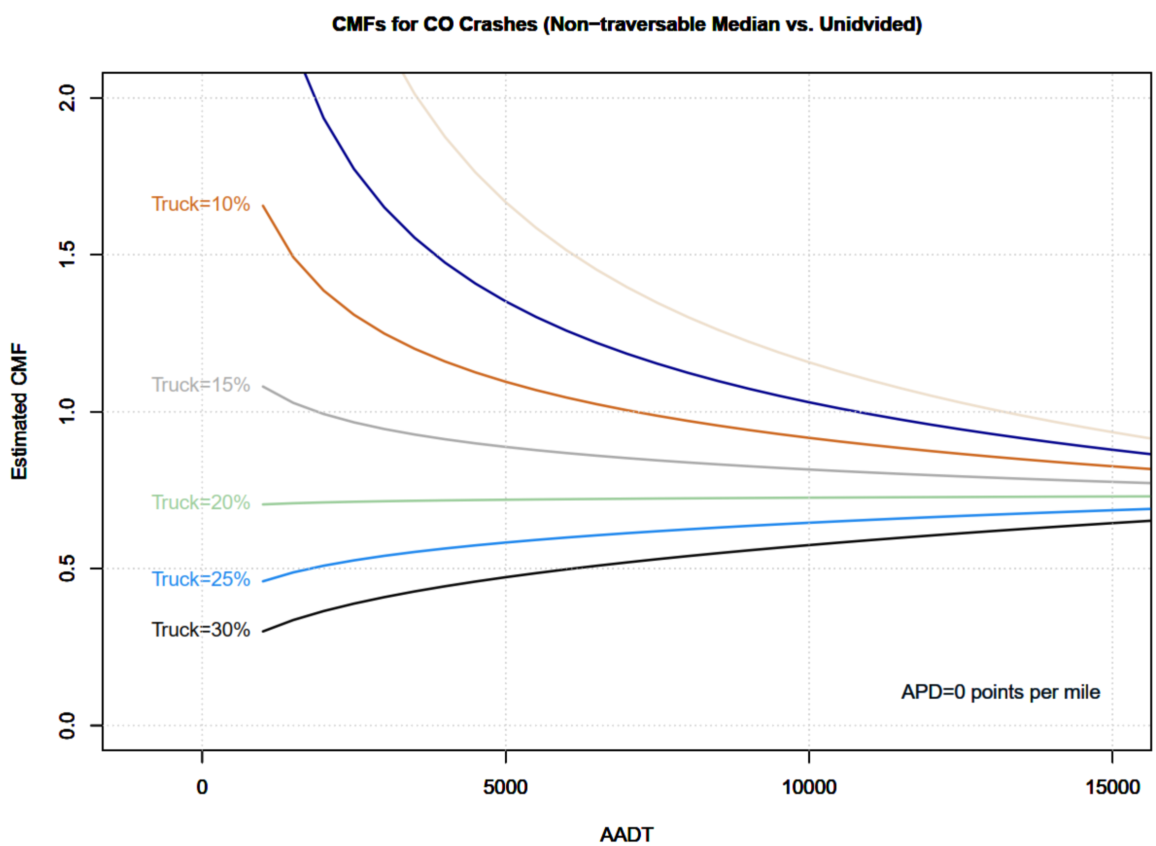
CMFs for CO Crashes (TWLTL vs. Unidvided)



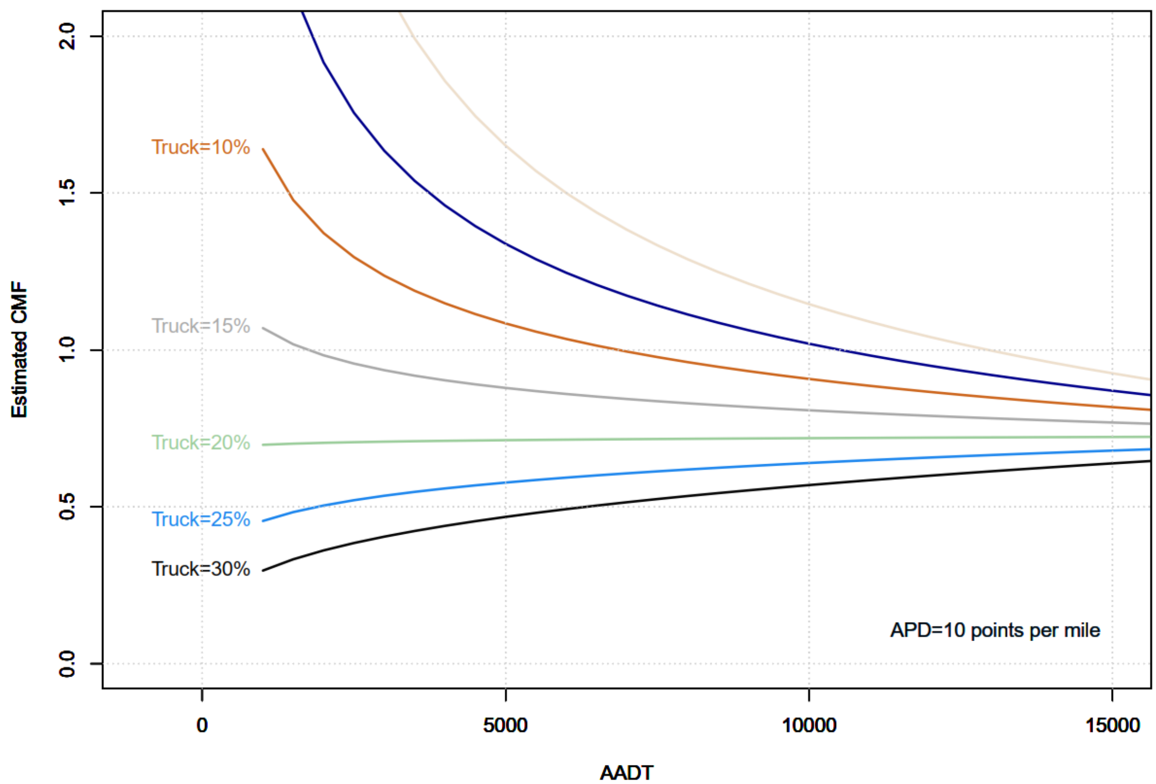

CMFs for CO Crashes (TWLTL vs. Unidvided)
Estimated CMF
2.0
1.5
1.0
0.5
0.0
Truck=5%
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=10 points per mile
0
5000
10000
15000
AADT


CMFs for CO Crashes (TWLTL vs. Unidvided)
Estimated CMF
2.0
1.5
1.0
0.5
0.0
Truck=5%
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=20 points per mile
0
5000
10000
15000
AADT

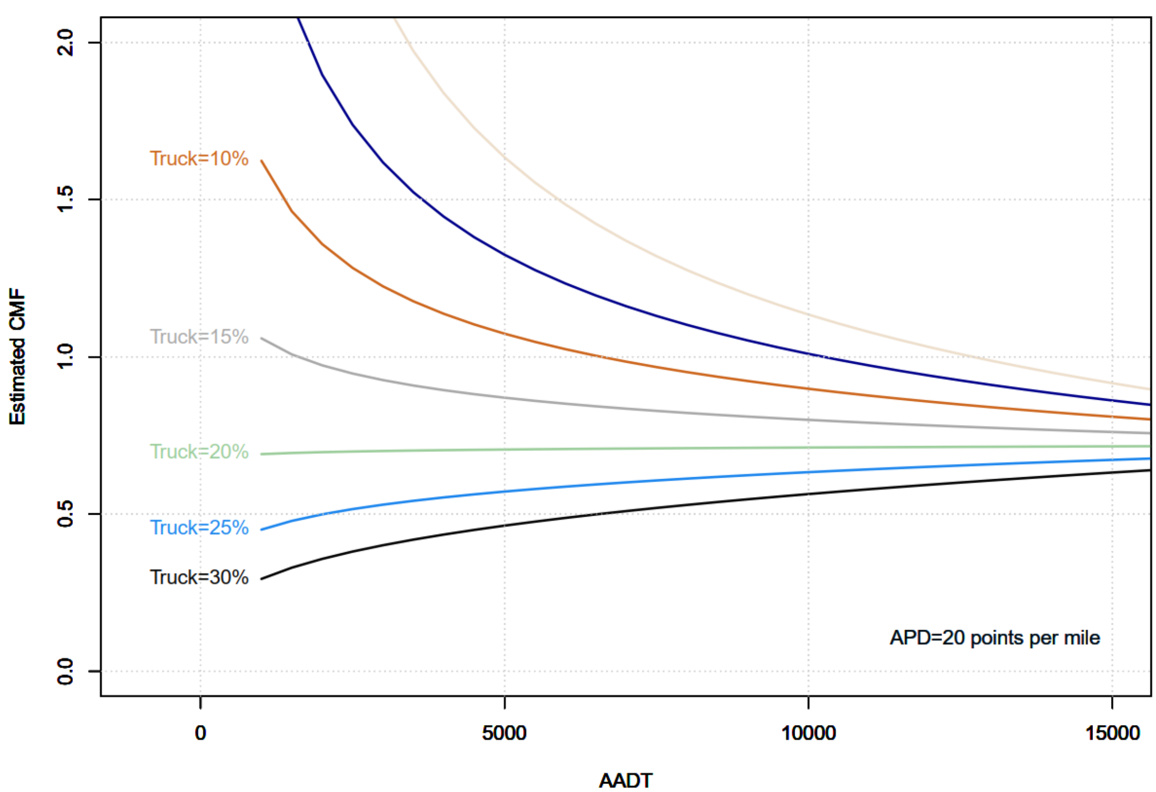

CMFs for CO Crashes (TWLTL vs. Unidvided)
Estimated CMF
AADT
Truck=5%
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=30 points per mile
0
5000
10000
15000
0.0
0.5
1.0
1.5
2.0


CMFs for CO Crashes (Non−traversable Median vs. Unidvided)
Estimated CMF
AADT
Truck=10%
Truck=15%
Truck=20%
Truck=25%
Truck=30%
APD=0 points per mile
0
5000
10000
15000
0.0
0.5
1.0
1.5
2.0

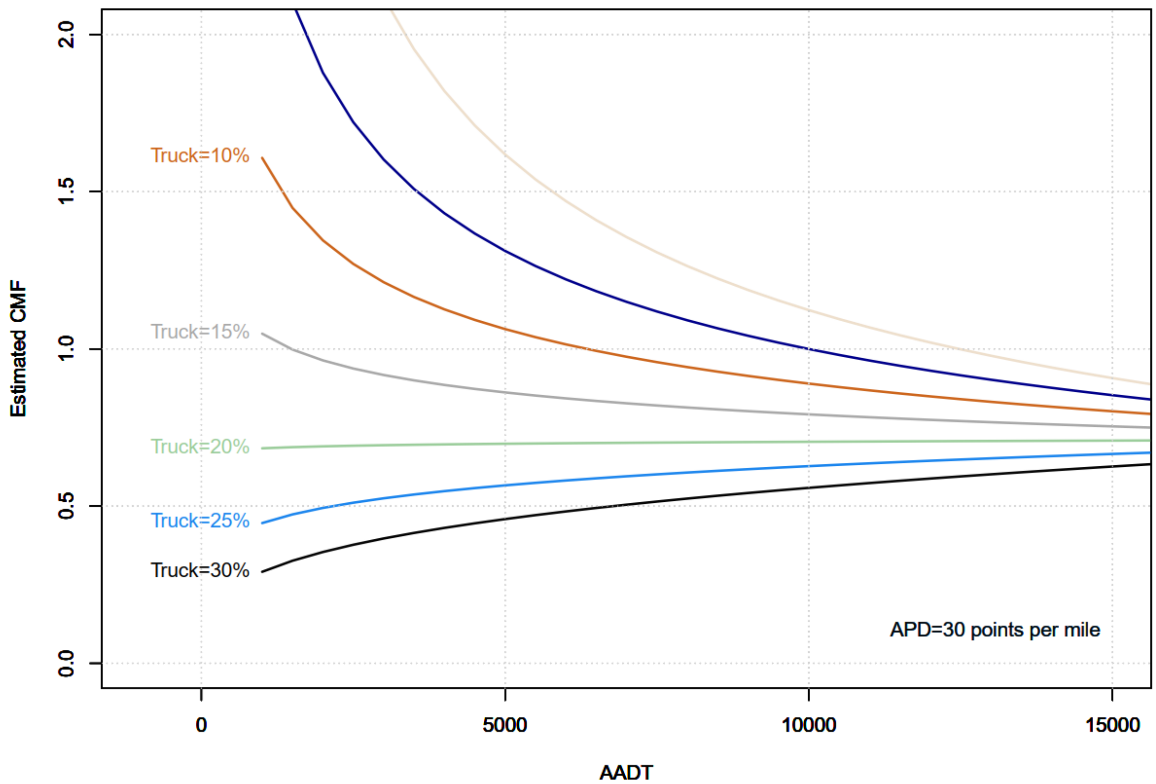
CMFs for CO Crashes (Non−traversable Median vs. Unidvided)



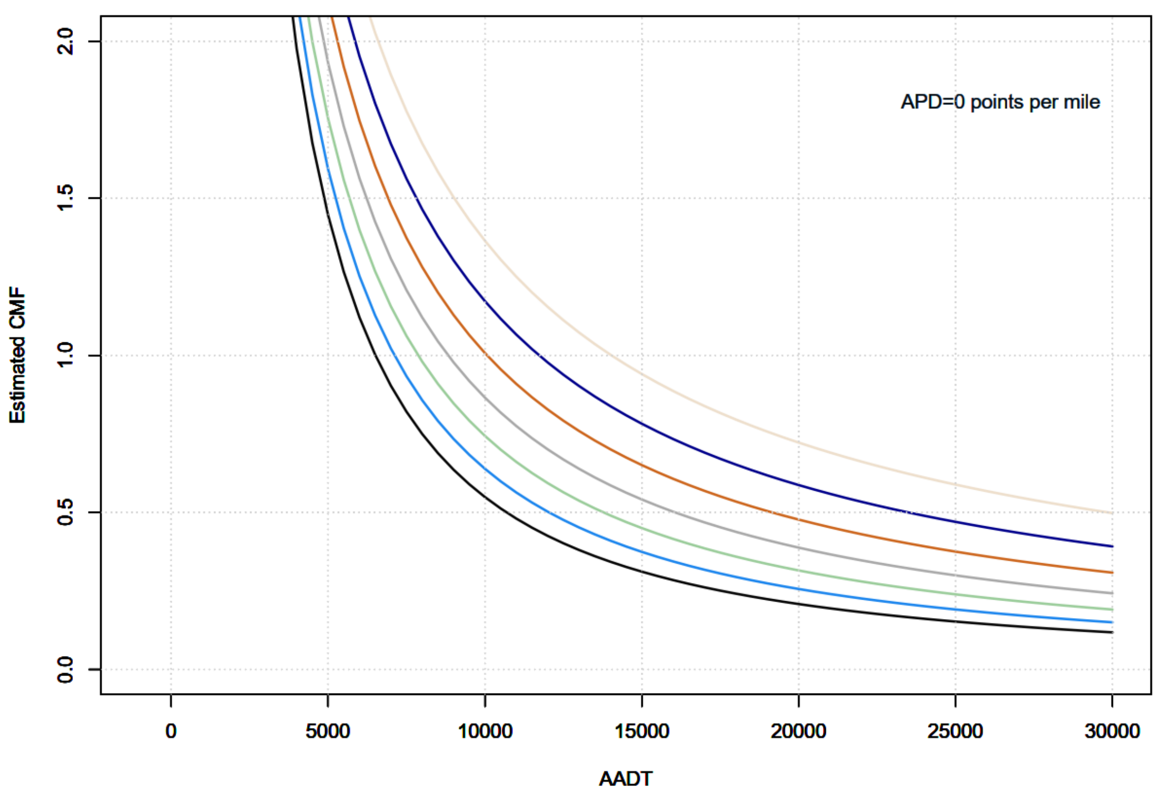
CMFs for CO Crashes (Non−traversable Median vs. Unidvided)



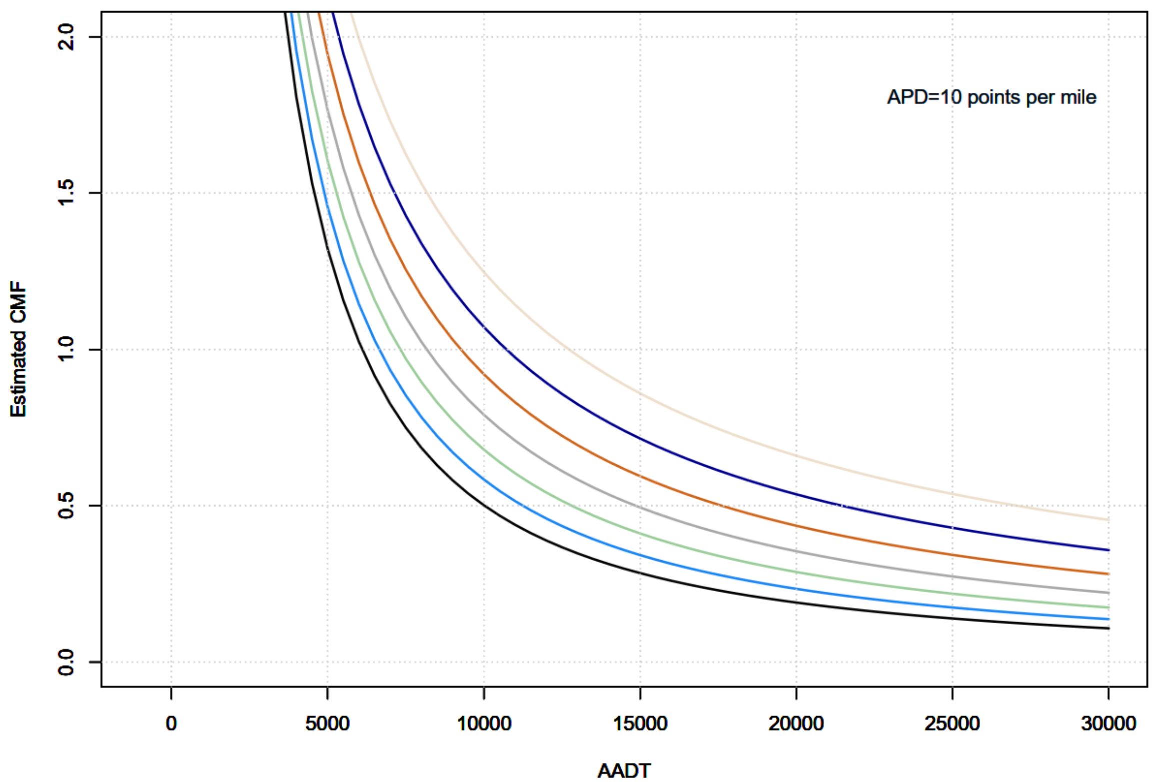
CMFs for CO Crashes (Non−traversable Median vs. Unidvided)



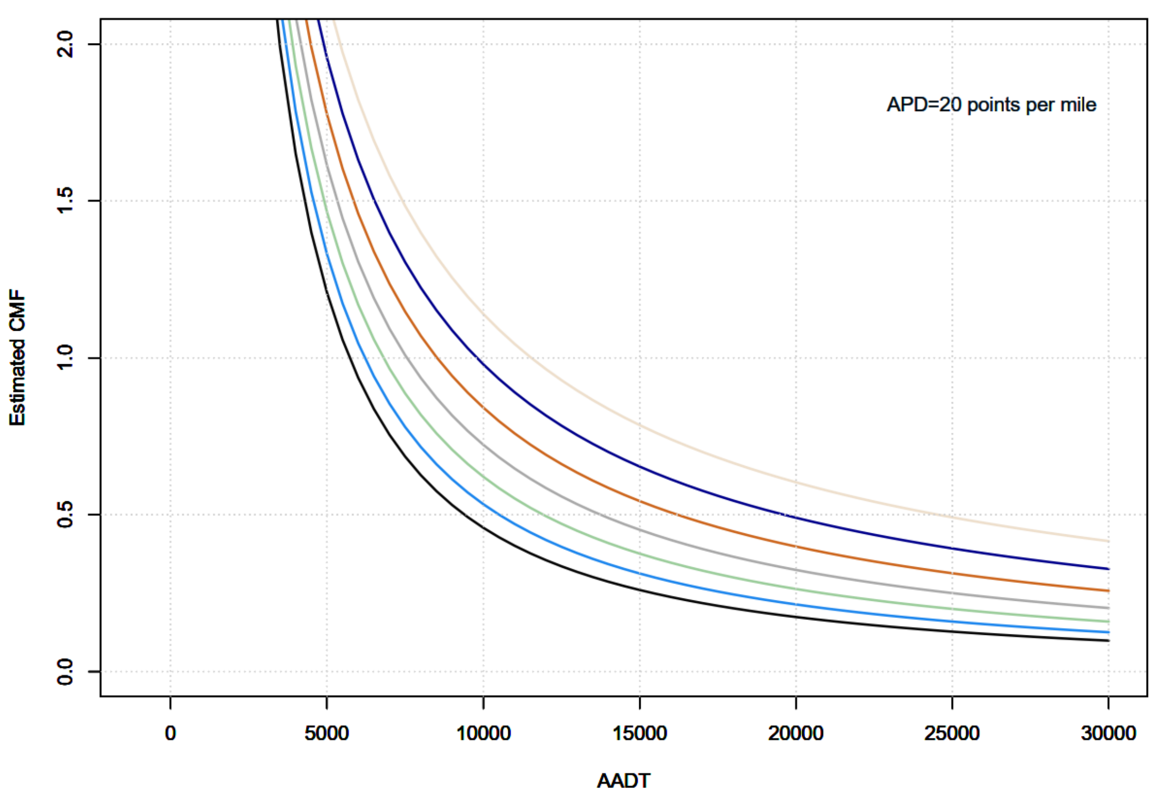
CMFs for CO Crashes (TWLTL vs. 4−ft Flush Median)

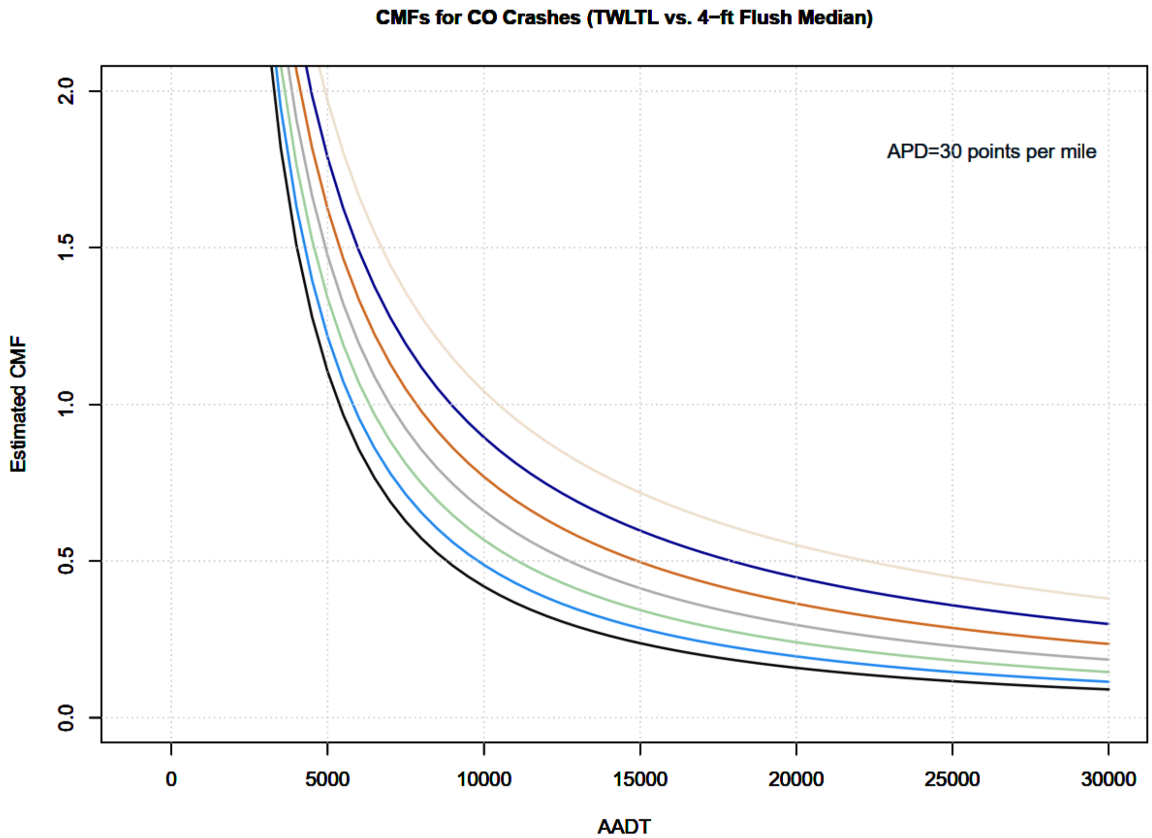


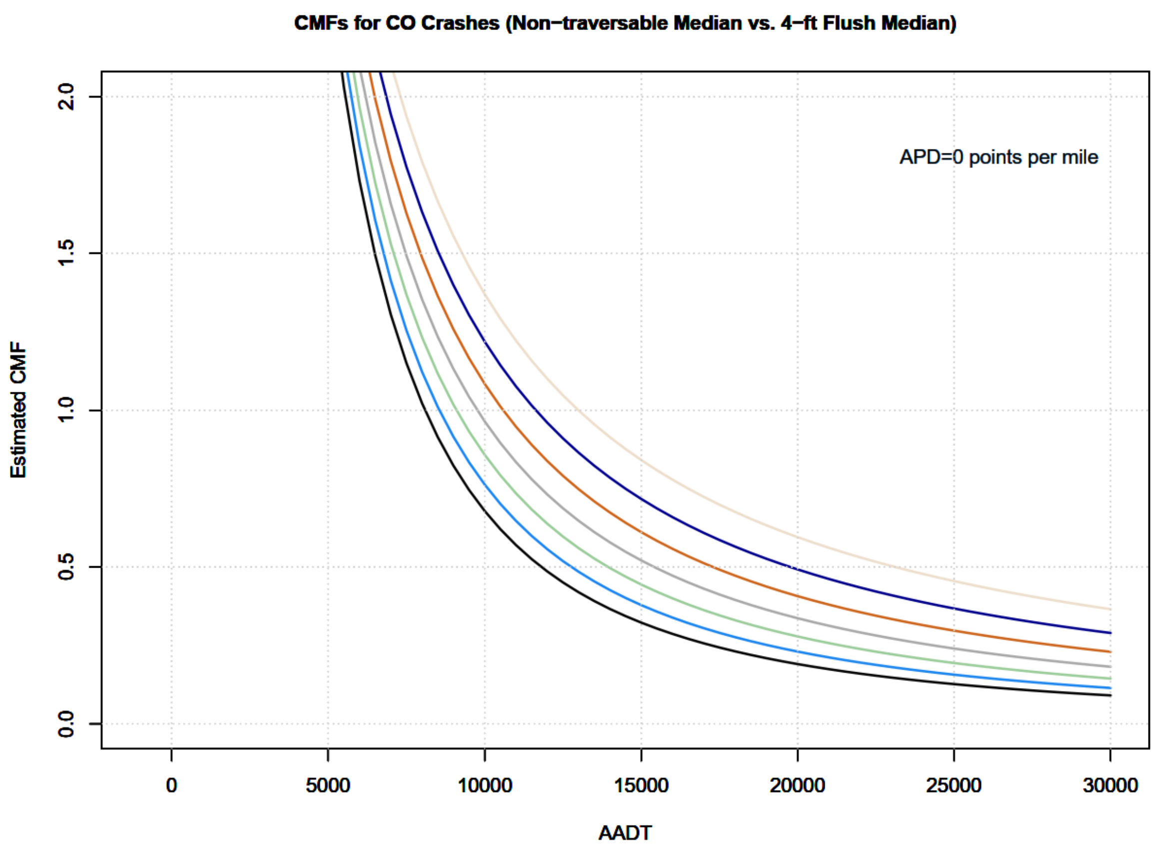
CMFs for CO Crashes (TWLTL vs. 4−ft Flush Median)

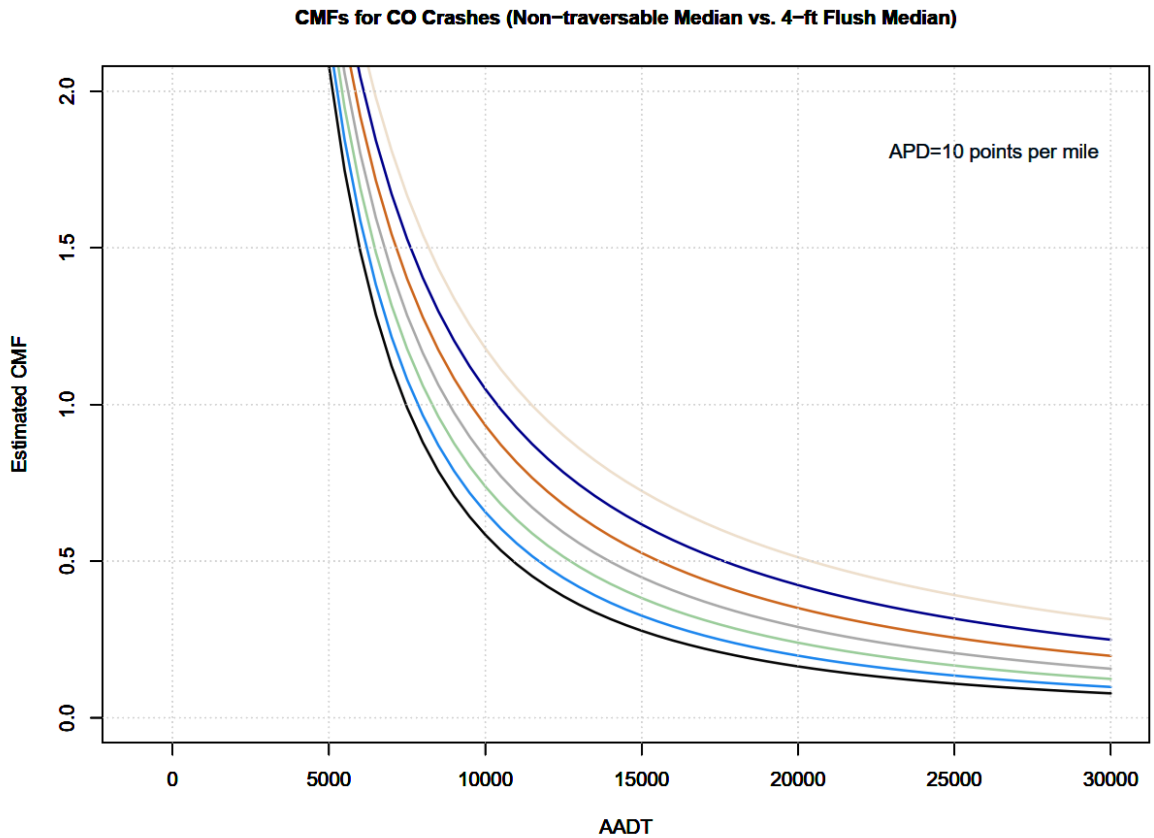


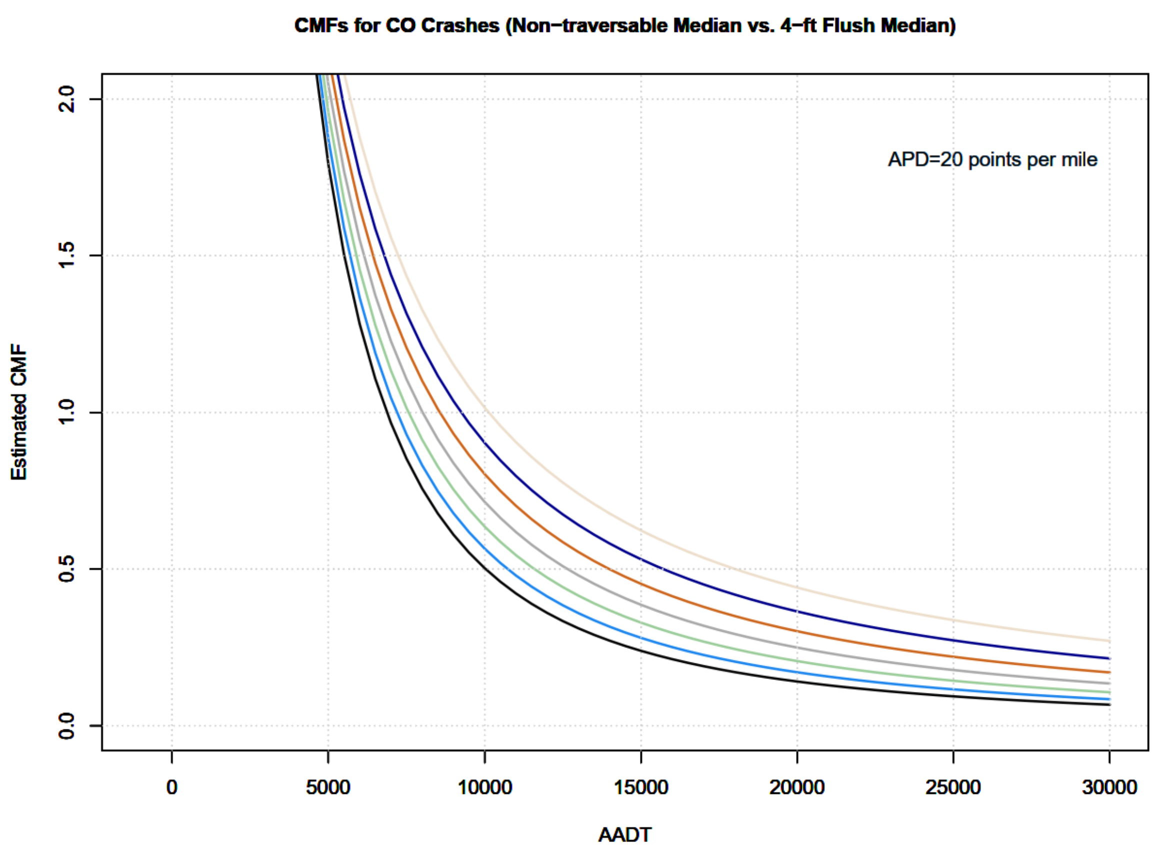
CMFs for CO Crashes (TWLTL vs. 4−ft Flush Median)

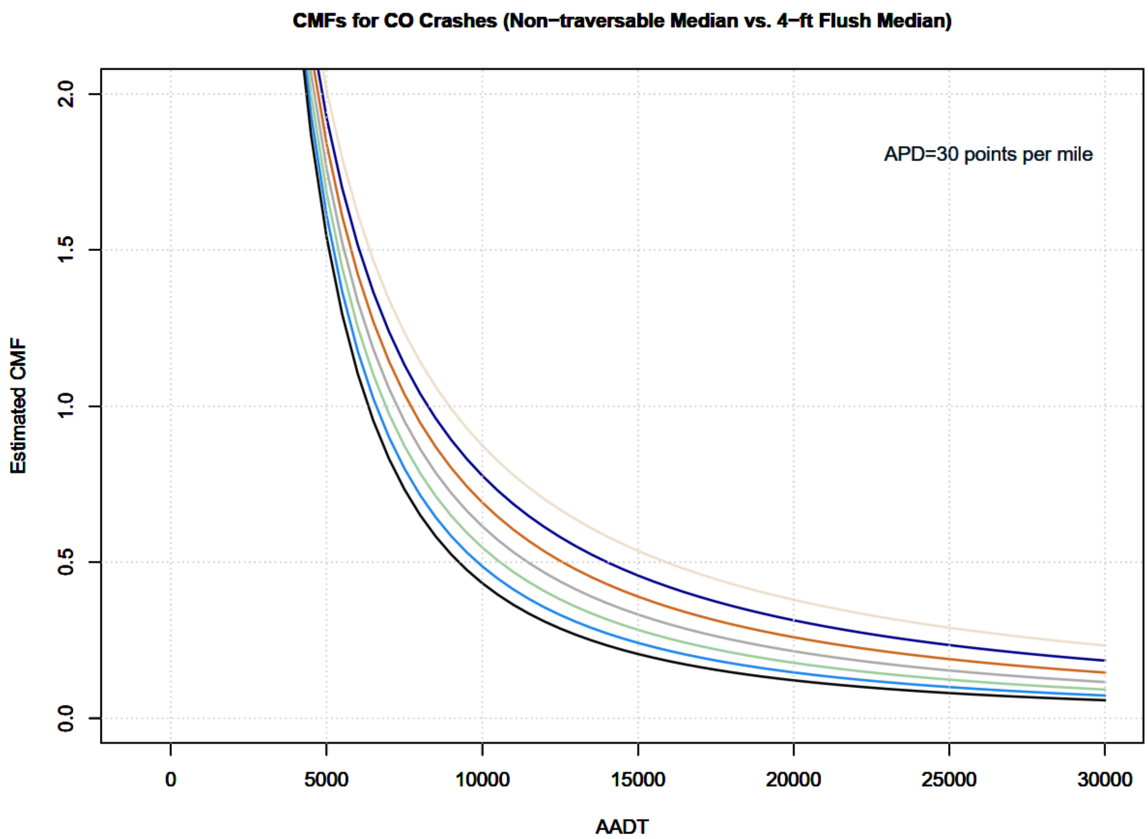



CMFs for CO Crashes (TWLTL vs. 4−ft Flush Median)
APD=30 points per mile
Estimated CMF
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000
20000
25000
30000
AADT


CMFs for CO Crashes (Non−traversable Median vs. 4−ft Flush Median)
APD=0 points per mile
Estimated CMF
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000
20000
25000
30000
AADT


CMFs for CO Crashes (Non−traversable Median vs. 4−ft Flush Median)
APD=10 points per mile
Estimated CMF
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000
20000
25000
30000
AADT


CMFs for CO Crashes (Non−traversable Median vs. 4−ft Flush Median)
APD=20 points per mile
Estimated CMF
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000
20000
25000
30000
AADT



CMFs for CO Crashes (Non−traversable Median vs. 4−ft Flush Median)
APD=30 points per mile
Estimated CMF
0.0
0.5
1.0
1.5
2.0
0
5000
10000
15000
20000
25000
30000
AADT

APPENDIX C. Estimated average CMFs for KAB and CO crashes.

Estimated average CMFs for KAB crashes

		Vehicle AADT																							
	Truck Percentage	<=5,000				>5,000 to 10,000				>10,000 to 15,000				>15,000 to 20,000				>20,000 to 25,000				>25,000			
		Access Point Density, AP/mile																							
		<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30
4-ft Flush Median	<=5%	0.41	0.43	0.45	0.40	0.57	0.59	0.62	0.55	0.65	0.67	0.70	0.62	0.70	0.73	0.76	0.68	0.75	0.78	0.81	0.72	0.79	0.82	0.85	0.76
	>5% to <=10%	0.37	0.38	0.40	0.36	0.60	0.62	0.65	0.57	0.73	0.76	0.79	0.70	0.83	0.86	0.90	0.80	0.91	0.95	0.99	0.88	0.99	N/A	N/A	N/A
	>10% to <=15%	0.34	0.35	0.37	0.32	0.63	0.65	0.68	0.60	0.82	0.85	0.89	0.79	0.98	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>15% to <=20%	0.31	0.32	0.34	0.30	0.66	0.69	0.71	0.63	0.92	0.96	1.00	0.89	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>20%	0.28	0.29	0.31	0.27	0.69	0.72	0.75	0.67	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TWLTL	<=5%	0.77	0.90	N/A	0.66	0.52	0.60	0.70	0.45	0.45	0.53	0.61	0.39	0.41	0.48	0.56	0.36	0.39	0.45	0.53	0.33	0.37	0.43	0.50	0.32
	>5% to <=10%	0.68	0.81	0.92	0.59	0.48	0.55	0.64	0.41	0.42	0.49	0.56	0.36	0.39	0.45	0.52	0.33	0.36	0.42	0.49	0.31	0.35	0.40	0.47	0.30
	>10% to <=15%	0.62	0.72	0.83	0.53	0.44	0.51	0.59	0.38	0.39	0.45	0.52	0.33	0.36	0.42	0.48	0.31	0.34	0.39	0.46	0.29	0.32	0.38	0.44	0.28
	>15% to <=20%	0.55	0.63	0.74	0.47	0.40	0.46	0.54	0.34	0.36	0.42	0.48	0.31	0.33	0.39	0.45	0.29	0.32	0.37	0.43	0.27	0.30	0.35	0.41	0.26
	>20%	0.49	0.57	0.66	0.42	0.37	0.43	0.49	0.32	0.33	0.38	0.45	0.28	0.31	0.36	0.42	0.27	0.29	0.34	0.40	0.25	0.28	0.33	0.38	0.24
Non-traversable	<=5%	N/A	N/A	N/A	N/A	0.86	0.92	0.99	0.80	0.57	0.61	0.65	0.53	0.44	0.47	0.50	0.41	0.36	0.39	0.41	0.34	0.31	0.33	0.35	0.29
	>5% to <=10%	N/A	N/A	N/A	N/A	0.68	0.73	0.78	0.63	0.49	0.52	0.56	0.45	0.39	0.42	0.45	0.37	0.33	0.36	0.38	0.31	0.29	0.32	0.34	0.27
	>10% to <=15%	N/A	N/A	N/A	N/A	0.54	0.58	0.62	0.50	0.42	0.45	0.48	0.39	0.35	0.38	0.41	0.33	0.31	0.33	0.36	0.29	0.28	0.30	0.32	0.26
	>15% to <=20%	0.77	0.80	0.87	0.70	0.43	0.46	0.49	0.40	0.36	0.38	0.41	0.33	0.32	0.34	0.36	0.29	0.29	0.31	0.33	0.27	0.27	0.29	0.31	0.25
	>20%	0.47	0.50	0.54	0.44	0.34	0.37	0.39	0.32	0.30	0.33	0.35	0.28	0.28	0.30	0.33	0.26	0.27	0.29	0.31	0.25	0.26	0.28	0.30	0.24

Notes: The CMF calculation base cross-section is undivided roadways. Cells with "N/A" are estimated with average CMFs greater than 1.00. The results are applicable to roadways with posted speed limits of 50 mph and higher.

Estimated average CMFs for CO crashes

		Vehicle AADT																							
	Truck Percentage	<=5,000				>5,000 to 10,000				>10,000 to 15,000				>15,000 to 20,000				>20,000 to 25,000				>25,000			
		Access Point Density, AP/mile																							
		<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30	<=10	>10 to 20	>20 to 30	>30
4-ft Flush Median	<=5%	0.29	0.33	0.39	0.25	0.72	0.83	0.95	0.63	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>5% to <=10%	0.22	0.25	0.29	0.19	0.67	0.78	0.89	0.59	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>10% to <=15%	0.16	0.19	0.22	0.14	0.63	0.73	0.84	0.55	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>15% to <=20%	0.13	0.15	0.17	0.11	0.60	0.69	0.79	0.52	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>20%	0.10	0.11	0.13	0.08	0.56	0.64	0.74	0.49	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TWLTL	<=5%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.95	0.96	N/A	N/A	0.91	0.93	N/A	N/A	0.88
	>5% to <=10%	0.95	N/A	N/A	0.91	0.94	N/A	N/A	0.90	0.94	N/A	N/A	0.90	0.94	N/A	N/A	0.90	0.94	N/A	N/A	0.89	0.94	N/A	N/A	0.89
	>10% to <=15%	0.63	0.66	0.70	0.60	0.77	0.81	0.85	0.74	0.84	0.88	0.93	0.80	0.88	0.93	0.98	0.84	0.92	0.97	N/A	0.88	0.95	N/A	N/A	0.90
	>15% to <=20%	0.43	0.45	0.47	0.41	0.63	0.67	0.70	0.60	0.75	0.78	0.83	0.71	0.83	0.87	0.92	0.79	0.90	0.95	N/A	0.86	0.96	N/A	N/A	0.91
	>20%	0.29	0.31	0.32	0.28	0.52	0.55	0.57	0.49	0.66	0.70	0.74	0.63	0.78	0.82	0.86	0.74	0.88	0.93	0.97	0.84	0.97	N/A	N/A	0.92
Non-traversable	<=5%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.98	0.98	0.97	0.99	0.84	0.83	0.83	0.85	0.75	0.74	0.73	0.76	0.68	0.68	0.67	0.69
	>5% to <=10%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.90	0.89	0.88	0.91	0.81	0.80	0.79	0.82	0.74	0.74	0.73	0.75	0.70	0.69	0.68	0.70
	>10% to <=15%	N/A	N/A	N/A	N/A	0.91	0.90	0.89	0.92	0.83	0.82	0.81	0.83	0.77	0.77	0.76	0.78	0.74	0.73	0.72	0.75	0.71	0.70	0.70	0.72
	>15% to <=20%	0.85	0.84	0.83	0.85	0.78	0.77	0.76	0.79	0.76	0.75	0.74	0.76	0.74	0.74	0.73	0.75	0.73	0.73	0.72	0.74	0.72	0.72	0.71	0.73
	>20%	0.60	0.59	0.59	0.61	0.67	0.66	0.65	0.67	0.69	0.69	0.68	0.70	0.71	0.71	0.70	0.72	0.73	0.72	0.71	0.73	0.74	0.73	0.72	0.75

Notes: The CMF calculation base cross-section is undivided roadways. Cells with "N/A" are estimated with average CMFs greater than 1.00. The results are applicable to roadways with posted speed limits of 50 mph and higher.