Phase I-II of the Minnesota *Highway Safety Manual* Calibration

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1. Scope of Calibration

The crash prediction models in the *Highway Safety Manual* (HSM) include a calibration factor to adjust the combined result of the safety performance functions (SPFs) and crash modification factors (CMFs) to match local conditions. Calibration factors are intended to account for variances between states in crash reporting thresholds, driver behaviors that influence crash frequency, driving conditions (for example, weather), terrain, etc. Therefore, it is important for all states to develop calibration factors in order to gain the greatest benefit from the HSM crash prediction models.

In developing the Minnesota HSM calibration factors, the scope of the calibration was limited to the Trunk Highway system of roads. Therefore, the calibration factors are appropriate when applying the HSM SPFs to U.S. and Minnesota State highways only. Additionally, for each crash prediction model, two regional calibration factors were developed for the Minnesota Trunk Highways. One calibration factor is specifically intended for the Minneapolis/St. Paul Metropolitan (Metro) district while the other calibration factor is for the remaining seven districts (referred to as Greater Minnesota).

To date, HSM calibration efforts have been completed for rural two-lane, two-way highways (Chapter 10 of the HSM) and rural expressways (Chapter 11 of the HSM). It is important to understand that the Minnesota definition of a rural expressway is typically a high-speed, multi-lane facility with a depressed grass median, limited number of at-grade intersections and occasional interchanges at high-volume cross streets. This represents a subset of the facility types covered in Chapter 11 of the HSM, which also could include rural multi-lane undivided and rural multi-lane divided with a narrow raised median (sometimes referred to as a conventional roadway in Minnesota). Additionally, the HSM intersection crash prediction models do not distinguish between undivided and divided facilities. However, the rural expressway intersection calibration factors was limited by removing intersections located on undivided and conventional divided segments.

2. Calibration Methodology for Rural Two-Lane, Two-Way Highways

2.1. Identification of Eligible Locations

The process of identifying locations that meet the definition of a rural two-lane, two-way highway began with the Minnesota Department of Transportation's (MnDOT) 2011 intersection and 2011 section toolkits. Roadway segments were identified from the section toolkit with the following criteria:

- Environment = Rural
- Design = Conventional
- Lanes = 2
- Median = None

The HSM includes separate crash prediction models for three-leg intersections with minor-road stop control (3ST), four-leg intersections with minor-road stop control (4ST), and four-leg signalized intersections (4SG). For each intersection type, locations were identified using the criteria listed in Table 1 in the intersection toolkit.

TABLE 1
Intersection Type Criteria for Rural Two-Lane, Two-Way Highways

Field Name	Three-Leg, Minor-Road Stop Controlled (3ST)	Four-Leg, Minor-Road Stop Controlled (4ST)	Four-Leg Signalized (4SG)
Intersection Type	Intersection	Intersection	Intersection
Intersection Description	"Tee" and "Wye"	Crossing at Right Angles and Crossing Skewed	Crossing at Right Angles and Crossing Skewed
Traffic Control Device	Thru/Yield and Thru/Stop	Thru/Yield and Thru/Stop	Signals
General Environment	Rural	Rural	Rural
Road Description of Primary Route	Two-Lane, Two-Way	Two-Lane, Two-Way	Two-Lane, Two-Way

Next, roadway segments and intersections were compared to the volume thresholds established in the HSM for the SPFs. The HSM intersection volume thresholds are for both the major and minor road average daily traffic (ADT) volumes. However, the intersection toolkit included a maximum leg ADT and the intersection approach volume. Therefore, the volume check for intersections was an approximation by first comparing the maximum leg ADT to the major road threshold and then by comparing the approach volume in the intersection toolkit to the sum of the HSM major and minor road ADT thresholds. This method does not directly ensure the minor road ADT threshold is not exceeded, but approximates based on the sum of the two. Table 2 lists the traffic volumes by facility type (intersection or roadway segment) for rural two-lane, two-way highways in Minnesota.

TABLE 2
Traffic Volume Thresholds by Facility Type for Rural Two-Lane, Two-Way Highways

Facility Type	Major Road ADT	Minor Road ADT	Approach Volume
Three-Leg, Minor-Road Stop Controlled (3ST)	19,500	4,300	23,800
Four-Leg, Minor-Road Stop Controlled (4ST)	14,700	3,500	18,200
Four-Leg Signalized (4SG)	25,200	12,500	37,700
Roadway Segment	17,800		

Note:
ADT = average daily traffic

Using aerial images and the MnDOT video log, MnDOT staff reviewed each of the identified locations that exceeded the HSM volume thresholds. Based on their review, the staff determined if locations met the design definition of a rural two-lane, two-way highway. Those locations that did not meet the definition were removed from all further analysis.

2.2. Determination of Appropriate Sample Size

The HSM recommends that for state-specific calibration, the sample should include 30 to 50 sites with a total observed crash history of at least 100 crashes per year. To select a sample size for intersection types, random samples ranging from 30 locations up to 350 locations were identified, including the number of crashes at the randomly selected intersections. [*Note: At this stage in the analysis, the anticipated plan was to develop two sets of calibration factors for Greater Minnesota, one for the northern half of the state and one for the southern half. It was later decided to keep Greater Minnesota as a single region.*] This revealed that in some cases, up to 300 or more intersections is needed to meet the HSM recommendation of 100 crashes per year. To manage the effort given the available resources, it was determined that 100 sites would be randomly selected for each calibration factor to be developed. Specific to 4SG intersections, 33 potential sites were identified statewide, so all sites were selected for calibration. Table 3 lists the number of crashes by intersection type that were used in the state-specific calibration.

TABLE 3
Crashes by Intersection Type and Region for a Range of Random Sample Sizes

Intersection Type	Region	Number of Locations*	Crashes for All Intersections (3 Years)			Total Crashes for Sample Size (3 Years)							
			Severe	Total	Average Annual	30 Sites	50 Sites	75 Sites	100 Sites	150 Sites	200 Sites	300 Sites	350 Sites
3ST	North	705	28	562	187.3	30	37	66	103	121	137	259	287
	South	476	15	505	168.3	28	35	90	86	160	203	296	—
	Metro	421	17	694	231.3	54	93	130	190	258	297	—	—
4ST	North	896	70	1,050	350.0	30	66	82	131	187	244	384	—
	South	783	46	1,012	337.3	26	49	108	125	209	227	454	—
	Metro	158	8	434	144.7	64	167	230	235	420	—	—	—
4SG	North	3	0	34	11.3	—	—	—	—	—	—	—	—
	South	5	10	47	15.7	—	—	—	—	—	—	—	—
	Metro	25	4	338	112.7	—	—	—	—	—	—	—	—

Notes:
* Number of locations and crash totals are prior to removing locations that exceed the volume threshold.
Source: 2011 Intersection Toolkit (2009-through-2011 crash records)

A similar exercise was completed for roadway segments, estimating how many segments identified in the section toolkit needed to be randomly selected to meet the HSM recommendations. After looking at sample sizes ranging from 30 roadway segments up to 75, it was determined that randomly selecting 300 miles of roads for each calibration factor would provide the desired level of quality. Table 4 lists the number of roadway segment crashes by region for the state-specific calibration.

TABLE 4
Roadway Segment Crashes by Region for a Range of Random Sample Sizes

Facility Type	Region	Total Number of Segments*	Total Mileage	Crashes for All segments (3 Years)			Total Crashes for Sample Size (3 Years)			Units of Measure
				Severe	Total	Average Annual	30 Sites	50 Sites	75 sites	
Rural Two-Lane, Two-Way Roadway Segment	North	643	5,288.7	200	3,628	1209.3	143	359	353	*Crashes*
							275.6	371.5	633.2	*Miles*
	South	410	3,123.0	136	3,032	1010.7	202	333	569	*Crashes*
							220.9	367.5	589.6	*Miles*
	Metro	88	330.5	34	1,212	404.0	434	696	-	*Crashes*
							124.3	194.2	-	*Miles*

Note:
*Number of segments and crash totals are prior to removing locations that exceed the volume threshold.

Source: 2011 Section Toolkit (2009-2011 crash records)

2.3. Collection of Data

Data collection was performed manually for each roadway segment and intersection. Google Earth® aerial images were used to collect all geometric information used in the SPFs and CMFs. For the roadway segments, Google Earth was also used to identify where roadway segments needed to be broken to separate tangents from horizontal curves and to keep each analysis segment homogeneous.

The MnDOT 2011 geographic information system (GIS) shapefile with traffic volumes was used to identify volumes for both roadway segments and intersections. If an intersection had a leg with an unreported traffic volume, the assumed volumes originated with the MnDOT Office of Transportation Data Analysis (TDA) for reporting to the Highway Performance Monitoring System (HPMS).

- City streets where population is less than 5,000, then ADT = 369
- City streets where population is 5,000 to 50,000, then ADT = 674
- City streets where population is more than 50,000, then ADT = 824
- Township roads, then ADT = 54
- Other roads = 4

Observed crash history for intersections was taken from the 2011 intersection toolkit, using the 3-year crash frequency based on data from 2009 through 2011. Because roadway segments from the section toolkit had to be split into subsegments, the Minnesota Crash Mapping Analysis Tool (MnCMAT) was used to export the 2009-through-2011 crash records. Then using GIS, crashes were assigned to each analysis segment, using a 25-foot buffer to allow for discrepancies between the crash coordinates and the GIS alignment. To be consistent with the HSM, only non-junction crashes were reported for the roadway segment analysis.

Note: During the data collection, some roadway segments and intersections were identified as not useable for the analysis. Possible explanations include the roadway segment/intersection was located in a suburban context; the facility type not truly fitting the two-lane, two-way description; etc. When such locations were encountered, they were removed from the data collection effort and the determination of a calibration factor. However, these locations were still used in the update to the HSM default tables.

3. Calibration Methodology for Rural Expressways

3.1. Identification of Eligible Locations

The process of identifying locations that meet the definition of a rural expressway began with MnDOT's 2012 intersection and 2012 section toolkits. Roadway segments were identified from the section toolkit with the following criteria:

- Environment = Rural
- Design = Expressway
- Lanes = 4, 6 or 8
- Median = Divided

The HSM includes separate crash prediction models for three-leg intersections with minor-road stop control (3ST), four-leg intersections with minor-road stop control (4ST), and four-leg signalized intersections (4SG). For each intersection type, locations were identified using the criteria listed in Table 5 in the intersection toolkit.

TABLE 5
Intersection Type Criteria for Rural Expressways

Field Name	Three-Leg, Minor-Road Stop Controlled (3ST)	Four-Leg, Minor-Road Stop Controlled (4ST)	Four-Leg Signalized (4SG)
Intersection Type	Intersection	Intersection	Intersection
Intersection Description	"Tee" and "Wye"	Crossing at Right Angles and Crossing Skewed	Crossing at Right Angles and Crossing Skewed
Traffic Control Device	Thru/Stop and Flashers – Amber/Red	Thru/Stop and Flashers – Amber/Red	Signals
General Environment	Rural	Rural	Rural
Road Description of Primary Route	4/6 Lanes Divided	4/6 Lanes Divided	4/6 Lanes Divided

Because the intersection toolkit does not identify that the intersection was located along an expressway rather than a conventional road, each intersection was manually reviewed to determine if it was part of the rural expressway system or the rural conventional road system. Additionally, MnDOT staff were consulted for intersections with unusual design or appeared to have had recent construction (converted to signalized, closed median, etc.) to determine if they should be eliminated from the pool of eligible locations.

Next, roadway segments and intersections were compared to the volume thresholds established in the HSM for the SPFs. The HSM intersection volume thresholds are for both the major and minor road ADT volumes. However, the intersection toolkit included a maximum leg ADT and the intersection approach volume. Therefore, the volume check for intersections was an approximation by first comparing the max leg ADT to the major road threshold and then by comparing the approach volume in the intersection toolkit to the sum of the HSM major and minor road ADT thresholds. This method does not directly ensure the minor road ADT threshold is not exceeded, but approximates based on the sum of the two. Table 6 lists the traffic volumes by facility type (intersection or roadway segment) for rural expressways in Minnesota.

Of all locations identified as a rural expressway, no segments or intersections exceeded the HSM volume thresholds.

TABLE 6
Traffic Volume Thresholds by Facility Type for Rural Expressways

Facility Type	Major Road ADT	Minor Road ADT	Approach Volume
Three-Leg, Minor-Road Stop Controlled (3ST)	78,300	23,000	101,300
Four-Leg, Minor-Road Stop Controlled (4ST)	78,300	7,400	85,700
Four-Leg Signalized (4SG)	43,500	18,500	62,000
Roadway Segment	89,300		

Note:
ADT = average daily traffic

3.2. Determination of Appropriate Sample Size

With over 800 miles of rural expressways in Minnesota, a sample-size analysis using data from the 2012 section toolkit was conducted to determine how many sites or miles should be included as the sample in the analysis. The methodology in this analysis is based on Appendix B of National Cooperative Highway Research Program (NCHRP) Project 20-07(332). This analysis was also conducted for 3ST and 4ST intersections in Greater Minnesota.

The standard error associated with the estimated calibration factor was calculated using various sample sizes. For each sample, qualified roadway segments or intersections were randomly selected. The selections include the observed crashes, applicable ADTs, and length (in the case of roadway segments). Ranged estimates of the calibration factor were produced by applying standard deviation values to the averaged calibration factor without the use of CMFs. The combination of a sufficiently low standard deviation of the estimated, averaged calibration factor; a large enough number of sites, and a large enough number of annual crashes were the ideal factors in selecting a sample size.

With the exception of 4ST intersections in Greater Minnesota, the entire set of applicable intersections statewide were analyzed due to a low population frequency. In Greater Minnesota, 75 sites were chosen for 4ST intersections and 50 sites were chosen for roadway segments.

3.3. Collection of Data

Data collection was performed manually for each roadway segment and intersection. Google Earth aerial images were used to collect all geometric information used in the SPFs. For the roadway segments, Google Earth was also used to identify where the segments needed to be partitioned to account for changes in design features such as median and shoulder width.

The MnDOT Traffic Forecasting & Analysis counts from 2011 and 2012 were used to identify volumes for roadway segments. Intersection volumes were provided by MnDOT in a form linkable to the intersections in the 2012 intersection toolkit. If an intersection had a leg with an unreported traffic volume, assumed volumes originated with the MnDOT Office of Transportation Data Analysis (TDA) for reporting to the Highway Performance Monitoring System (HPMS).

- City streets where population is less than 5,000, then ADT = 369
- City streets where population is 5,000 to 50,000, then ADT = 674
- City streets where population is more than 50,000, then ADT = 824
- Township roads, then ADT = 54
- Other roads = 4

Observed crash history for intersections was taken from the 2012 intersection toolkit, using the 3-year crash frequency based on data from 2010 through 2012. Because roadway segments from the section toolkit had to be split into subsegments, MnCMAT was used to export the 2010-through-2012 crash records. Then using GIS, a spatial join was performed to assign crashes to the applicable analysis segments, using a 25-foot buffer to allow for discrepancies between the crash coordinates and the GIS alignment. To be consistent with the HSM, only non-junction crashes were reported for the roadway segment analysis.

Note: During the data collection, some roadway segments or portions of segments were identified as not useable for the analysis. Possible explanations include the roadway segment/intersection was located in a suburban context; the facility type not truly fitting the expressway description; etc. When such locations were encountered, they were removed from the data collection effort and the determination of a calibration factor. However, these locations were still used in updates to the HSM default tables.

4. Minnesota Default Tables

The HSM crash prediction models include several default tables. In some cases, the default tables are applied to the crash model outputs; converting total predicted crashes into crash severity or different crash types. Other default tables are used in the computation of a CMF; proportion of nighttime crashes for the intersection lighting CMF.

The level of information needed to update the default tables for rural two-lane, two-way and rural expressways required information that exceeded what is contained in Minnesota's section and intersection toolkits. Also, MnCMAT doesn't have the ability to reliably identify the intersections or roadway segments that meet the definition of either calibration effort. For these reasons, the default tables were updated using data from the Transportation Information System (TIS). Locations that were identified as eligible through the high-level screening process were given to MnDOT. MnDOT then provided the crash data for the locations to update the default tables. [*Note: This process happened before the collection of the information for the random samples. So if a location was removed from the random sample during the calibration, its crash information remained in the data set used to update the default tables. The impact to the default tables is nominal since few locations were screened out during the data collection phase.*]

Rural two-lane, two-way roadway segments and intersections were updated using the 2009-through-2011 Minnesota crash records, while the rural expressways table updates used the 2010-through-2012 crash records.

4.1. Rural Two-Lane, Two-Way Highways

Updated of the default HSM tables for rural two-lane, two-way highways includes three roadway segment tables and three intersection tables. Each table presents the HSM default value, and the same distribution for statewide Minnesota, Greater Minnesota, and Metro.

4.1.1. Roadway Segments

Table 7 shows the distribution of crash severities on roadway segments for rural two-lane, two-way highways. Table 8 shows the distribution by collision type for specific crash severity levels on roadway segments for rural two-lane, two-way highways. Table 9 shows nighttime crashes as a proportion of total crashes by severity level on roadway segments for rural two-lane, two-way highways.

TABLE 7
HSM Default and Minnesota Distribution of Crash Severity for Rural Two-Lane, Two-Way Highway Segments

	HSM Default Values*	Minnesota**		
Crash Severity Level	Percentage of Total Roadway Segment Crashes	Greater Minnesota	Metro	Statewide
Fatal	1.3	1.9%	1.0%	1.8%
Incapacitating Injury	5.4	3.2%	1.8%	3.0%
Non-incapacitating Injury	10.9	15.5%	10.2%	14.8%
Possible Injury	14.5	20.1%	21.7%	20.3%
Total Fatal plus Injury	32.1	40.7%	34.7%	39.9%
Property Damage Only	67.9	59.3%	65.3%	60.1%
Total	100.0	100.0%	100.0%	100.0%

Notes:
*Based on Highway Safety Information System (HSIS) data for Washington State (2002 through 2006)
**Minnesota non-junction-only crashes (2009 through 2011)
Source: Table is based on Table 10-3 of the HSM.

TABLE 8

HSM Default and Minnesota Distribution by Collision Type for Specific Crash Severity Levels on Rural Two-Lane, Two-Way Highway Segments

Collision Type	HSM Default Values*			Minnesota**								
	Percentage of Total Roadway Segment Crashes by Crash Severity Level			Greater Minnesota			Metro			Statewide		
	Fatal and Injury	Property Damage Only	Total (All Severity Levels Combined)	Fatal and Injury	PDO	Total	Fatal and Injury	PDO	Total	Fatal and Injury	PDO	Total
Single-Vehicle Crashes												
Collision with animal	3.8	18.4	12.1	8.6%	25.3%	19.2%	6.6%	31.6%	23.3%	8%	26%	20%
Collision with bicycle	0.4	0.1	0.2	0.1%	0.0%	0.0%	0.5%	0.0%	0.2%	0%	0%	0%
Collision with pedestrian	0.7	0.1	0.3	0.7%	0.0%	0.3%	0.5%	0.0%	0.2%	1%	0%	0%
Overturned	3.7	1.5	2.5	33.8%	22.3%	26.5%	19.3%	8.5%	12.1%	32%	20%	25%
Run-off-the-road	54.5	50.5	52.1	22.1%	23.6%	23.0%	21.1%	17.1%	18.4%	22%	23%	22%
Other single-vehicle crash	0.7	2.9	2.1	2.9%	6.0%	4.9%	4.3%	6.9%	6.0%	3%	6%	5%
Total single-vehicle crashes	**63.8**	**73.5**	**69.3**	**68.3%**	**77.2%**	**73.9%**	**52.3%**	**64.1%**	**60.2%**	**66%**	**75%**	**72%**
Multiple-Vehicle Crashes												
Angle collision	10.0	7.2	8.5	4.1%	1.9%	2.7%	5.7%	2.8%	3.8%	4%	2%	3%
Head-on collision	3.4	0.3	1.6	7.4%	1.1%	3.4%	8.0%	1.5%	3.6%	7%	1%	3%
Rear-end collision	16.4	12.2	14.2	10.8%	8.5%	9.3%	22.3%	20.5%	21.1%	12%	10%	11%
Sideswipe collision	3.8	3.8	3.7	6.3%	7.6%	7.1%	6.1%	7.2%	6.9%	6%	8%	7%
Other multiple-vehicle collision	2.6	3.0	2.7	3.1%	3.8%	3.5%	5.7%	4.0%	4.5%	3%	4%	4%
Total multiple-vehicle crashes	**36.2**	**26.5**	**30.7**	**31.7%**	**22.8%**	**26.1%**	**47.7%**	**35.9%**	**39.8%**	**34%**	**25%**	**28%**
Total Crashes	100.0	100.0	100.0	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100%	100%	100%

Notes:

*Based on Highway Safety Information System (HSIS) data for Washington State (2002 through 2006)

**Minnesota non-junction-only crashes (2009 through 2011)

Source: Based on Table 10-4 in the HSM

TABLE 9
HSM Default and Minnesota Nighttime Crashes as a Proportion of Total Crashes by Severity Level on Rural Two-Lane, Two-Way Highway Segments

Region	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occurred at Night
	Fatal and Injury	PDO	Total
HSM Default Values*	0.382	0.618	0.370
Greater Minnesota**	0.105	0.214	0.319
Metro**	0.078	0.214	0.292
Statewide**	0.101	0.214	0.315

Notes:
*Based on Highway Safety Information System (HSIS) data for Washington State (2002 through 2006)
**Minnesota non-junction-only crashes (2009 through 2011)

Source: Based on Table 10-12 of the HSM

4.1.2. Intersections

Table 10 shows the distribution of collision type by intersection type on rural two-lane, two-way highways. Table 11 shows the distribution of crash severity by intersection type on rural two-lane, two-way highways. Table 12 shows nighttime crashes as a proportion of total crashes by intersection type on rural two-lane, two-way highways.

TABLE 10

HSM Default and Minnesota Distribution of Collision Type by Intersection Type on Rural Two-Lane, Two-Way Highways

	HSM Default Values*			Minnesota**								
	Percentage of Total Crashes			Greater Minnesota			Metro			Statewide		
Crash Severity Level	**3ST**	**4ST**	**4SG**	**3ST**	**4ST**	**4SG**	**3ST**	**4ST**	**4SG**	**3ST**	**4ST**	**4SG**
Fatal	1.7	1.8	0.9	0.83%	1.8%	1.4%	0.5%	1.0%	0.7%	0.7%	1.7%	0.8%
Incapacitating injury	4.0	4.3	2.1	2.7%	3.8%	4.1%	1.5%	1.0%	0.4%	2.3%	3.3%	1.0%
Non-incapacitating injury	16.6	16.2	10.5	13.9%	16.2%	12.3%	11.2%	12.0%	8.7%	12.9%	15.5%	9.3%
Possible injury	19.2	20.8	20.5	22.4%	21.1%	27.4%	20.9%	27.9%	26.8%	21.8%	22.4%	26.9%
Total fatal plus injury	41.5	43.1	34.0	39.9%	43.0%	45.2%	34.1%	41.9%	36.6%	37.7%	42.8%	38.0%
Property damage only	58.5	56.9	66.0	60.1%	57.0%	54.8%	65.9%	58.1%	63.4%	62.3%	57.2%	62.0%
Total	**100.0**	**100.0**	**100.0**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Notes:

*Based on Highway Safety Information System (HSIS) data for California (2002 through 2006)

**Minnesota junction crashes (2009 through 2011)

3ST = three-leg intersection with minor-road stop control

4ST = four-leg intersection with minor-road stop control

4SG = four-leg signalized intersection

Source: Based on Table 10-5 of the HSM

TABLE 11

HSM Default and Minnesota Distribution of Crash Severity by Intersection Type on Rural Two-Lane, Two-Way Highways

Collision Type	HSM Default Values*									Minnesota**								
	Percentage of Total Crashed by Collision Type									Statewide								
	3ST			4ST			4SG			3ST			4ST			4SG		
	Fatal and Injury	PDO	Total	Fatal and Injury	PDO	Total	Fatal and Injury	PDO	Total	Fatal and Injury	PDO	Total	Fatal and Injury	PDO	Total	Fatal and Injury	PDO	Total
Single-Vehicle Crashes																		
Collision with animal	0.8	2.6	1.9	0.6	1.4	1.0	0.0	0.3	0.2	3.4%	19.9%	13.7%	2.8%	13.9%	9.2%	0.0%	3.2%	2.0%
Collision with bicycle	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Collision with pedestrian	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Overturned	2.2	0.7	1.3	0.6	0.4	0.5	0.3	0.3	0.3	19.6%	9.9%	13.6%	12.2%	9.2%	10.5%	2.4%	0.6%	1.3%
Run-off-the-road	24.0	24.7	24.4	9.4	14.4	12.2	3.2	8.1	6.4	17.2%	17.2%	17.2%	10.6%	12.5%	11.7%	2.1%	5.0%	3.9%
Other single-vehicle crash	1.1	2.0	1.6	0.4	1.0	0.8	0.3	1.8	0.5	6.5%	9.1%	8.1%	3.2%	4.9%	4.2%	1.5%	3.0%	2.4%
Total single-vehicle crashes	**28.3**	**30.2**	**29.4**	**11.2**	**17.4**	**14.7**	**4.0**	**10.7**	**7.6**	**46.6%**	**56.0%**	**52.5%**	**28.9%**	**40.5%**	**35.5%**	**6.0%**	**11.7%**	**9.5%**
Multiple-Vehicle Crashes																		
Angle collision	27.5	21.0	23.7	53.2	35.4	43.1	33.6	24.2	27.4	14.6%	8.7%	10.9%	36.1%	20.2%	27.0%	23.9%	11.3%	16.1%
Head-on collision	8.1	3.2	5.2	6.0	2.5	4.0	8.0	4.0	5.4	4.3%	1.5%	2.6%	3.5%	1.0%	2.1%	3.9%	3.0%	3.3%
Rear-end collision	26.0	29.2	27.8	21.0	26.6	24.2	40.3	43.8	42.6	20.7%	18.7%	19.4%	17.4%	17.9%	17.7%	49.8%	51.2%	50.7%
Sideswipe collision	5.1	13.1	9.7	4.4	14.4	10.1	5.1	15.3	11.8	4.6%	8.3%	6.9%	5.7%	10.3%	8.4%	0.6%	9.1%	5.9%
Other multiple-vehicle collision	5.0	3.3	4.2	4.2	3.7	3.9	9.0	2.0	5.2	9.1%	6.8%	7.7%	8.4%	10.1%	9.4%	15.7%	13.7%	14.5%
Total multiple-vehicle crashes	**71.7**	**69.8**	**70.6**	**88.8**	**82.6**	**85.3**	**96.0**	**89.3**	**92.4**	**53.4%**	**44.0%**	**47.5%**	**71.1%**	**59.5%**	**64.5%**	**94.0%**	**88.3%**	**90.5%**
Total Crashes	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Notes:

*Based on Highway Safety Information System (HSIS) data for California (2002 through 2006)

** Minnesota junction crashes (2009 through 2011)

3ST = three-leg intersection with minor-road stop control

4ST = four-leg intersection with minor-road stop control

4SG = four-leg signalized intersection

Source: Based on Table 10-6 of the HSM

TABLE 12
HSM Default and Minnesota Nighttime Crashes as a Proportion of Total Crashes by Intersection Type on Rural Two-Lane, Two-Way Highways

Intersection Type	HSM Default Values*	Minnesota**		
	Proportion of Crashes that Occur at Night*	Greater	Metro	Statewide
3ST	0.260	0.261	0.232	0.250
4ST	0.244	0.191	0.152	0.184
4SG	0.286	0.014	0.066	0.057

Notes:
*Based on Highway Safety Information System (HSIS) data for California (2002 through 2006)
**Minnesota junction crashes (2009 through 2011)
3ST = three-leg intersection with minor-road stop control
4ST = four-leg intersection with minor-road stop control
4SG = four-leg signalized intersection
Source: Based on Table 10-15 of the HSM

4.2. Rural Expressways

Updated of the default HSM tables for rural expressways includes two roadway segment tables and two intersection tables. Each table presents the HSM default value, and the same distribution for statewide Minnesota, Greater Minnesota, and Metro.

4.2.1. Roadway Segments

Table 13 shows the distribution by collision type for specific crash severity levels on roadway segments for rural expressways. Table 14 shows nighttime crashes as a proportion of total crashes by severity level on roadway segments for rural expressways.

TABLE 13

HSM Default and Minnesota Distribution by Collision Type for Specific Crash Severity Levels for Rural Expressway Segments

Collision Type	HSM Default Values				Minnesota**											
	Proportion of Total Roadway Segment Crashes by Crash Severity Level				Greater Minnesota				Metro				Statewide			
	Total	Fatal and Injury	Fatal and Injury*	PDO	Total	Fatal and Injury	Fatal and Injury*	PDO	Total	Fatal and Injury	Fatal and Injury*	PDO	Total	Fatal and Injury	Fatal and Injury*	PDO
Head-on	0.006	0.013	0.018	0.002	0.036	0.038	0.049	0.035	0.038	0.038	0.065	0.037	0.036	0.038	0.053	0.035
Side-swipe	0.043	0.027	0.022	0.053	0.082	0.044	0.034	0.100	0.081	0.034	0.022	0.106	0.081	0.042	0.032	0.102
Rear-end	0.116	0.163	0.114	0.088	0.142	0.152	0.128	0.137	0.374	0.411	0.315	0.353	0.189	0.207	0.164	0.180
Angle	0.043	0.048	0.045	0.041	0.036	0.038	0.036	0.035	0.040	0.034	0.065	0.044	0.037	0.037	0.042	0.037
Single	0.768	0.727	0.778	0.792	0.577	0.612	0.615	0.559	0.331	0.350	0.337	0.320	0.527	0.557	0.561	0.512
Other	0.024	0.022	0.023	0.024	0.128	0.117	0.138	0.133	0.137	0.133	0.196	0.139	0.130	0.120	0.149	0.135

Notes:
*Using the KABCO scale, these include only KAB crashes (K = fatal injury, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, and O = no injury)
**Minnesota non-junction-only crashes (2010 through 2012)

Source: Based on Table 11-6 of the HSM

TABLE 14
HSM Default and Minnesota Nighttime Crashes as a Proportion of Total Crashes by Severity Level for Rural Expressway Segments

	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occurred at Night
Roadway Type	Fatal and Injury	PDO	Total
HSM Default Values	0.323	0.677	0.426
Greater Minnesota*	0.328	0.343	0.338
Metro*	0.221	0.341	0.298
Statewide*	0.305	0.343	0.330

Notes:
*Minnesota non-junction-only crashes (2010 through 2012)
Source: Based on Table 11-19 of the HSM

4.2.2. Intersections

Table 15 shows the distribution of intersection type by collision type and crash severity for rural expressways. Table 16 shows the nighttime crashes as a proportion of total crashes by intersection type for rural expressways.

TABLE 15

HSM Default and Minnesota Distribution of Intersection Crashes by Collision Type and Crash Severity for Rural Expressways

Collision Type	HSM Default Values				Minnesota**											
	Proportion of Total Roadway Segment Crashes by Crash Severity Level				Greater Minnesota				Metro				Statewide			
	Total	Fatal and Injury	Fatal and Injury*	PDO	Total	Fatal and Injury	Fatal and Injury*	PDO	Total	Fatal and Injury	Fatal and Injury*	PDO	Total	Fatal and Injury	Fatal and Injury*	PDO
Three-Leg Intersections with Minor Road Stop Control (3ST)																
Head-on	0.029	0.043	0.052	0.020	0.051	0.025	0.029	0.064	0.067	0.054	0.067	0.075	0.055	0.033	0.036	0.067
Side-swipe	0.133	0.058	0.057	0.179	0.117	0.038	0.014	0.159	0.080	0.018	0.000	0.112	0.107	0.033	0.012	0.147
Rear-end	0.289	0.247	0.142	0.315	0.132	0.114	0.087	0.142	0.184	0.214	0.133	0.168	0.146	0.140	0.095	0.149
Angle	0.263	0.369	0.381	0.198	0.305	0.500	0.638	0.200	0.160	0.232	0.333	0.121	0.266	0.430	0.583	0.179
Single	0.234	0.219	0.284	0.244	0.298	0.304	0.217	0.295	0.362	0.375	0.333	0.355	0.315	0.322	0.238	0.311
Other	0.052	0.064	0.084	0.044	0.097	0.019	0.014	0.139	0.147	0.107	0.133	0.168	0.110	0.042	0.036	0.147
Four-Leg Intersections with Minor Road Stop Control (4ST)																
Head-on	0.016	0.018	0.023	0.015	0.039	0.015	0.009	0.056	0.040	0.039	0.065	0.041	0.040	0.022	0.025	0.053
Side-swipe	0.107	0.042	0.040	0.156	0.088	0.050	0.052	0.116	0.119	0.068	0.065	0.173	0.096	0.055	0.056	0.128
Rear-end	0.228	0.213	0.108	0.240	0.133	0.107	0.043	0.151	0.119	0.117	0.065	0.122	0.129	0.110	0.049	0.145
Angle	0.395	0.534	0.571	0.292	0.365	0.533	0.612	0.247	0.353	0.476	0.587	0.224	0.362	0.516	0.605	0.243
Single	0.202	0.148	0.199	0.243	0.262	0.207	0.172	0.301	0.224	0.184	0.109	0.265	0.253	0.201	0.154	0.294
Other	0.051	0.046	0.059	0.055	0.112	0.088	0.112	0.129	0.144	0.117	0.109	0.173	0.120	0.096	0.111	0.138

TABLE 15

HSM Default and Minnesota Distribution of Intersection Crashes by Collision Type and Crash Severity for Rural Expressways

	HSM Default Values				Minnesota**											
	Proportion of Total Roadway Segment Crashes by Crash Severity Level				Greater Minnesota				Metro				Statewide			
Collision Type	Total	Fatal and Injury	Fatal and Injury*	PDO	Total	Fatal and Injury	Fatal and Injury*	PDO	Total	Fatal and Injury	Fatal and Injury*	PDO	Total	Fatal and Injury	Fatal and Injury*	PDO
Four-Leg Signalized Intersections (4SG)																
Head-on	0.054	0.083	0.093	0.034	0.024	0.050	0.091	0.011	0.035	0.015	0.027	0.044	0.031	0.030	0.051	0.031
Side-swipe	0.106	0.047	0.039	0.147	0.048	0.000	0.000	0.074	0.075	0.031	0.081	0.095	0.064	0.017	0.051	0.087
Rear-end	0.492	0.472	0.314	0.505	0.554	0.535	0.455	0.564	0.549	0.527	0.405	0.559	0.551	0.530	0.424	0.561
Angle	0.256	0.315	0.407	0.215	0.211	0.307	0.318	0.160	0.207	0.336	0.324	0.149	0.208	0.323	0.322	0.153
Single	0.062	0.041	0.078	0.077	0.076	0.030	0.000	0.101	0.059	0.053	0.081	0.061	0.066	0.043	0.051	0.077
Other	0.030	0.041	0.069	0.023	0.087	0.079	0.136	0.090	0.075	0.038	0.081	0.092	0.080	0.056	0.102	0.091

Notes:

*Using the KABCO scale, these include only KAB crashes (K = fatal injury, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, and O = no injury)

**Minnesota non-junction-only crashes (2010 through 2012)

Source: Based on Table 11-9 of the HSM

TABLE 16
HSM Default and Minnesota Nighttime Crashes as a Proportion of Total Crashes by Intersection Type for Rural Expressways

Intersection Type	HSM Default Values	Minnesota*		
	Proportion of Crashes that Occur at Night*	Greater	Metro	Statewide
3ST	0.276	0.291	0.319	0.299
4ST	0.273	0.281	0.284	0.282

Notes:
*Minnesota junction crashes (2010 through 2012)
3ST = three-leg intersection with minor-road stop control
4ST = four-leg intersection with minor-road stop control

Source: Based on Table 10-24 of the HSM

5. Calibration Results

Analysis spreadsheet tools developed in conjunction with NCHRP 17-38 were used to predict the average crash frequency of an applicable roadway segment or intersection given the site conditions. These tools were converted to organize the data into one row for each location (instead of one tab for each location) to accommodate a large data set for the applicable roadway types and features: roadway segments and 3ST, 4ST, and 4SG intersections for rural two-lane, two-way highways and rural expressways.

The main outputs of the converted tool are predicted crashes and calibration factors. For each facility type and by Greater Minnesota and Metro regions, the ratio of observed-to-predicted crashes was calculated, resulting in the facility type's calibration factor. Calibration results are presented in the following sections and also summarized in Attachment A.

5.1. Rural Two-Lane, Two-Way Highways

Table 17 summarizes the calibration factors for rural two-lane, two-way highway facility types for the Greater Minnesota and Metro regions. With the exception of 4SG intersections, all of these calibration factors are less than one, indicating that the HSM models over-predict the number of crashes that occur on rural two-lane, two-way highways in Minnesota.

TABLE 17
Calibration Factors for Roadway Segments and Intersections on Rural Two-Lane, Two-Way Highways in the Greater Minnesota and Metro Regions

Rural Two-Lane, Two-Way Highways	Greater Minnesota			Metro		
	Number of Locations	Observed Crashes (3 years*)	Minnesota Calibration Factor	Number of Locations	Observed Crashes (3 years*)	Minnesota Calibration Factor
Roadway Segments						
Two-lane, two-way roadway segments (Cr)	42 (326 miles)	207	0.41	73 (276 miles)	953	0.58
Intersections						
3ST – Three-leg intersection with minor-road stop control (Ci)	100	72	0.71	100	198	0.63
4ST – Four-leg intersections with minor-road stop control (Ci)	100	100	0.45	100	259	0.69
4SG – Four-leg signalized intersections (Ci)	31	392	1.22	🡐 Calibration factor is statewide because it includes all eligible locations in Minnesota		

Notes:
*Minnesota crashes (2009 through 2011)
Ci = calibration factor for intersection
Cr = calibration factor for roadway segment

5.2. Rural Expressways

Tables 18 and 19 show the calibration factors for rural expressway facility types (roadway segments and intersections, respectively) for the Greater Minnesota and Metro regions. With the exception of thru stop-controlled intersections in Greater Minnesota, all of these calibration factors are less than one, indicating that the HSM models over-predict the number of crashes that occur on Minnesota rural expressways, and under-predict the number at 3ST and 4ST intersections in the Greater Minnesota region.

TABLE 18

Calibration Factors for Roadway Segments on Rural Expressways in the Greater Minnesota and Metro Regions

Severity Level: Total						Fatal and Injury	Fatal and Injury*
				Non-Junction Crashes			
Region	Calibration Factor	Length (miles)	Vehicle Miles Traveled	Crash Density	Crash Rate	Calibration Factor	
Greater Minnesota	0.69	423	4,811,569	1.4	0.35	0.43	0.28
Metro	0.53	108	3,119,834	2.9	0.28	0.39	0.22

Notes:
*Using the KABCO scale, these include only KAB crashes (K = fatal injury, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, and O = no injury)

Sources: 2012 Section Toolkit and the Minnesota Crash Mapping Analysis Tool (MnCMAT) (2010-2012 crashes)

TABLE 19

Calibration Factors for Intersections on Rural Expressways in the Greater Minnesota and Metro Regions

Severity Level: Total					Fatal and Injury	Fatal and Injury*
			Junction Crashes			
Intersection Type/ Region	Calibration Factor	Number of Intersections	Crash Density	Crash Rate	Calibration Factor	
3ST						
Greater Minnesota	2.32	93	1.15	0.29	2.48	1.91
Metro	0.74	31	0.84	0.10	0.87	0.48
4ST						
Greater Minnesota**	1.87	75	1.43	0.35	2.38	1.75
Metro	0.88	36	1.60	0.18	1.08	0.78
4SG						
Statewide	0.39	40	6.17	0.69	0.30	0.21

Notes:
*Using the KABCO scale, these include only KAB crashes (K = fatal injury, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, and O = no injury)

**4ST in the Greater Minnesota region is a sample of the available applicable intersections.

3ST = three-leg intersection with minor-road stop control
4ST = four-leg intersection with minor-road stop control
4SG = four-leg signalized intersection

Source: 2012 Intersection Toolkit (2010-through-2012 crashes)

6. Evaluation of Model Fit

Following the development of a calibration factor, the fit of the calibrated model has to be tested to ensure the model results are reasonable given the local conditions and crash history. Where the model fit is determined to be beyond the acceptable range, caution should be used in the application of the model results.

6.1. Methodology

A cumulative residuals (CURE) analysis was performed to determine if the model bias for each facility type is within the acceptable range (example shown as Figure 1). The preparation and analysis of the CURE plots for the crash prediction models is based on the residuals, or difference, between the observed and calibrated predicted crashes—shown as the blue line in Figure 1. Generally speaking, where the residuals remain relatively small and don't result in a consistent upward or downward trend, the models can be determined to have little bias and are a good fit for Minnesota highways and intersections.

Upper and lower limits used to roughly demonstrate the boundaries within which the CURE series remains unbiased were produced from the standard deviation of the sum of residuals. The independent variables across which the cumulative residual series were plotted are segment length and the average daily traffic (ADT) volume for roadway segments, and minor-road and major-road entering ADT volumes for intersections. The two sets of upper- and lower-limit boundaries are two standard deviations (approximately 95 percent and includes the area between the purple lines) and one-half standard deviation (approximately 40 percent and includes the area between the red lines).

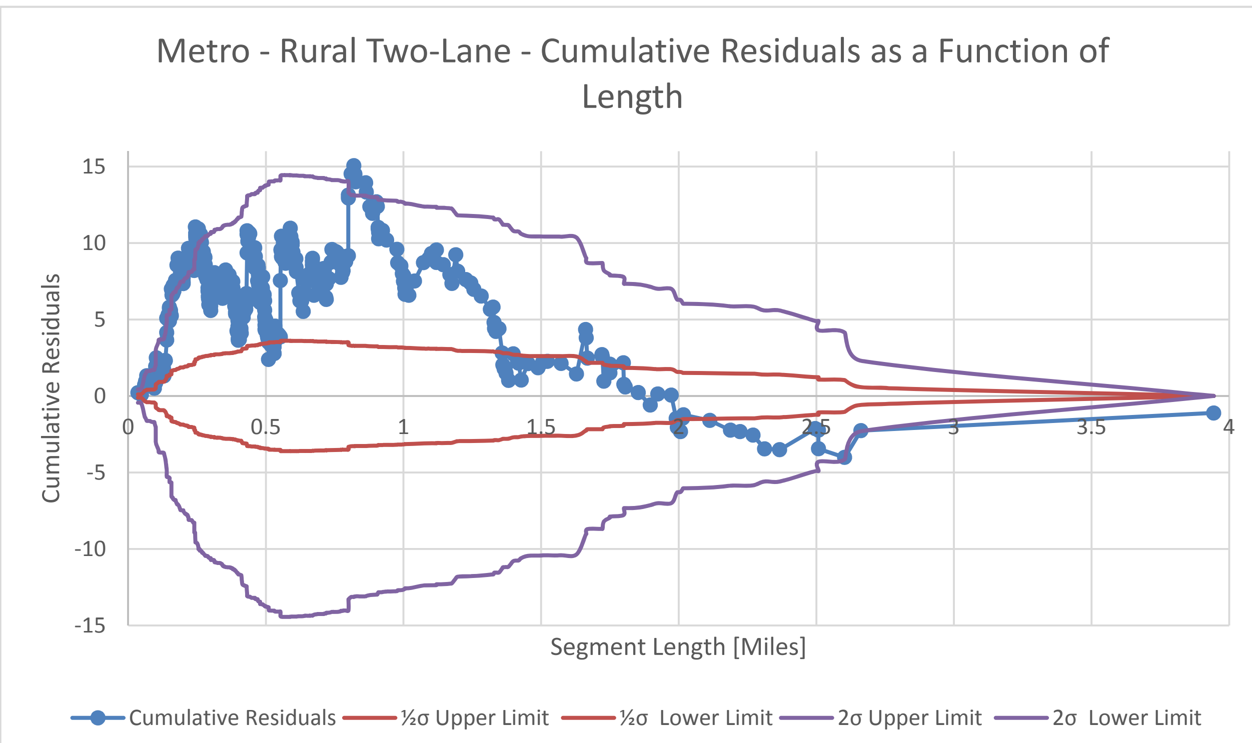


FIGURE 1
Example CURE Plot

6.2. Results

Cumulative residual plots for rural two-lane, two-way highways and rural expressways are provided in Attachment B.

With large portions of the CURE series values lying within the two sigma boundaries for most CURE plots [within the purple lines], most of the models are considered to demonstrate an acceptable fit—further model refinement or development is not required. CURE plots using roadway segment length or intersection minor-road entering ADT volume were generally considered to have a poorer fit or less correlation to crashes than their roadway segment ADT and intersection major-road entering ADT counterparts.

In interpreting the model fit from the CURE plots, recall that the boundary limits are two and one-half standard deviations, which in an assumed normal distribution equate to approximately 95 percent and 40 percent of the values. A rough interpretation of the CURE plots would be if at least 40 percent of the cumulative residuals series values are within one-half sigma, and at least 95 percent of these values are within two sigma, then the model combined with the applied calibration factor could be an unbiased or good fit.

The crash prediction model with the poorest fit were rural expressway 3ST intersections, whose CURE plots had a large amount of values exceed the two-sigma values. Before using the calibrated rural expressway 3ST crash prediction models, consideration should be given to the level of bias seen in the CURE plots. Otherwise, use of the remaining calibrated HSM SPFs in situations that fit the context described at the beginning of this technical memorandum are acceptable.

Regarding the rural expressway 3ST models, an effort was made to determine if refining the model—develop new model coefficients—would be a cost-effective way to improve the accuracy, and consequently usefulness, of the rural expressway 3ST models. The trial estimation, completed using the statistical testing software SAS , combined Greater Minnesota and Metro data into a single dataset. While the attempt did reveal that it may be possible to improve the fit of the model to the data (that is, increase the R^2 value); it did not however, result in significant improvements in the CURE plot. So while the results were inconclusive, it does indicate that model refinement is a potential approach to improve the results that requires less effort than model development.

ATTACHMENT A

Minnesota Calibration Factors

TABLE A-1
Minnesota Calibration Factors for HSM Crash Prediction Models (Total Crashes)

Facility Type	Greater Minnesota	Metro Minnesota
Rural Tow-Lane, Two-Way Highways*		
2U – Roadway Segments	0.41	0.58
3ST – Three-leg intersection with minor-road stop control	0.71	0.63
4ST – Four-leg intersections with minor-road stop control	0.45	0.69
4SG – Four-leg signalized intersections	1.22	
Rural Expressway (Rural Multi-Lane Divided)**		
4D – Roadway Segments	0.69	0.53
3ST – Three-leg intersection with minor-road stop control	2.32	0.74
4ST – Four-leg intersections with minor-road stop control	1.87	0.88
4SG – Four-leg signalized intersections	0.39	

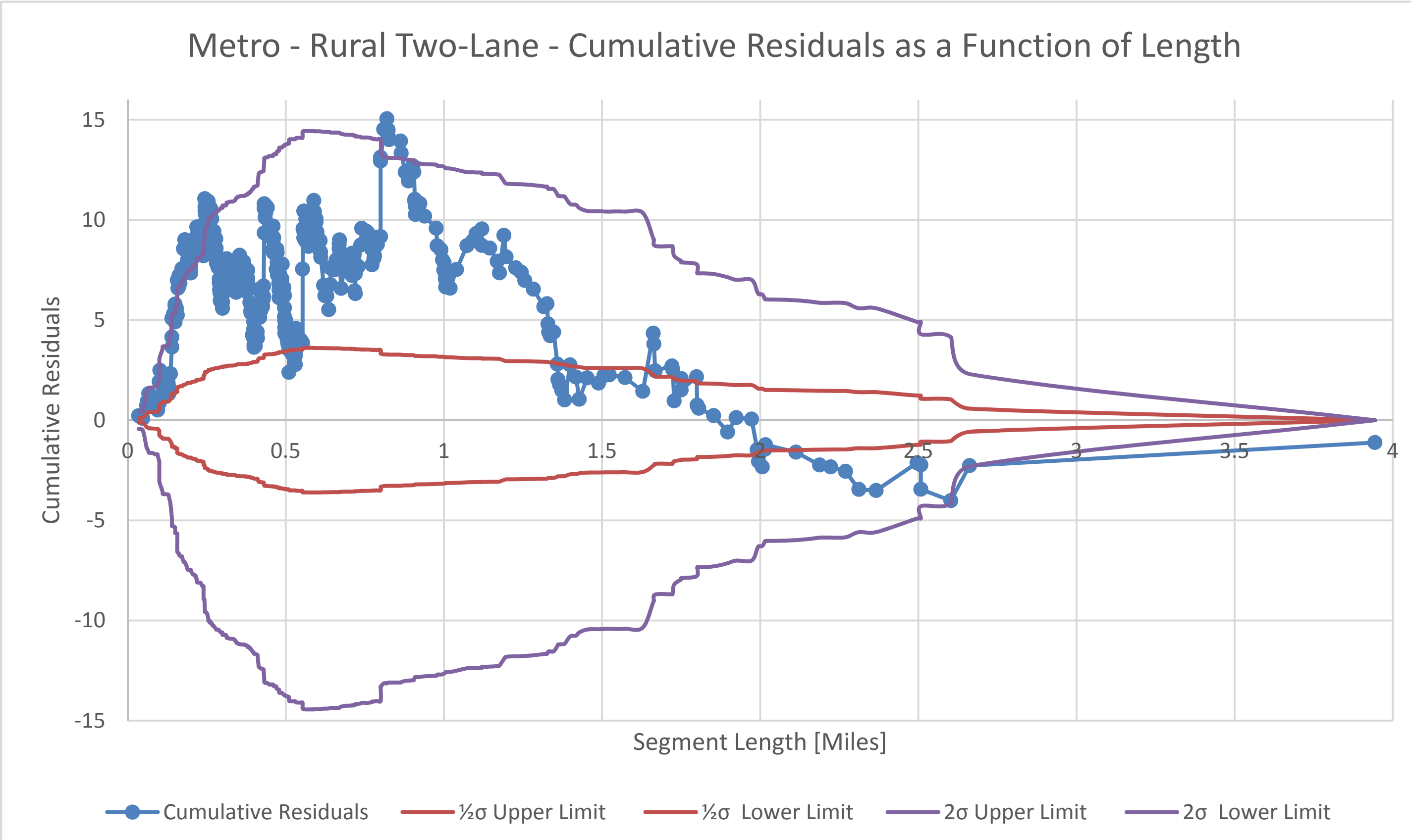
Notes:
*Minnesota crashes (2009 through 2011)
**Minnesota crashes (2010 through 2012)

ATTACHMENT B

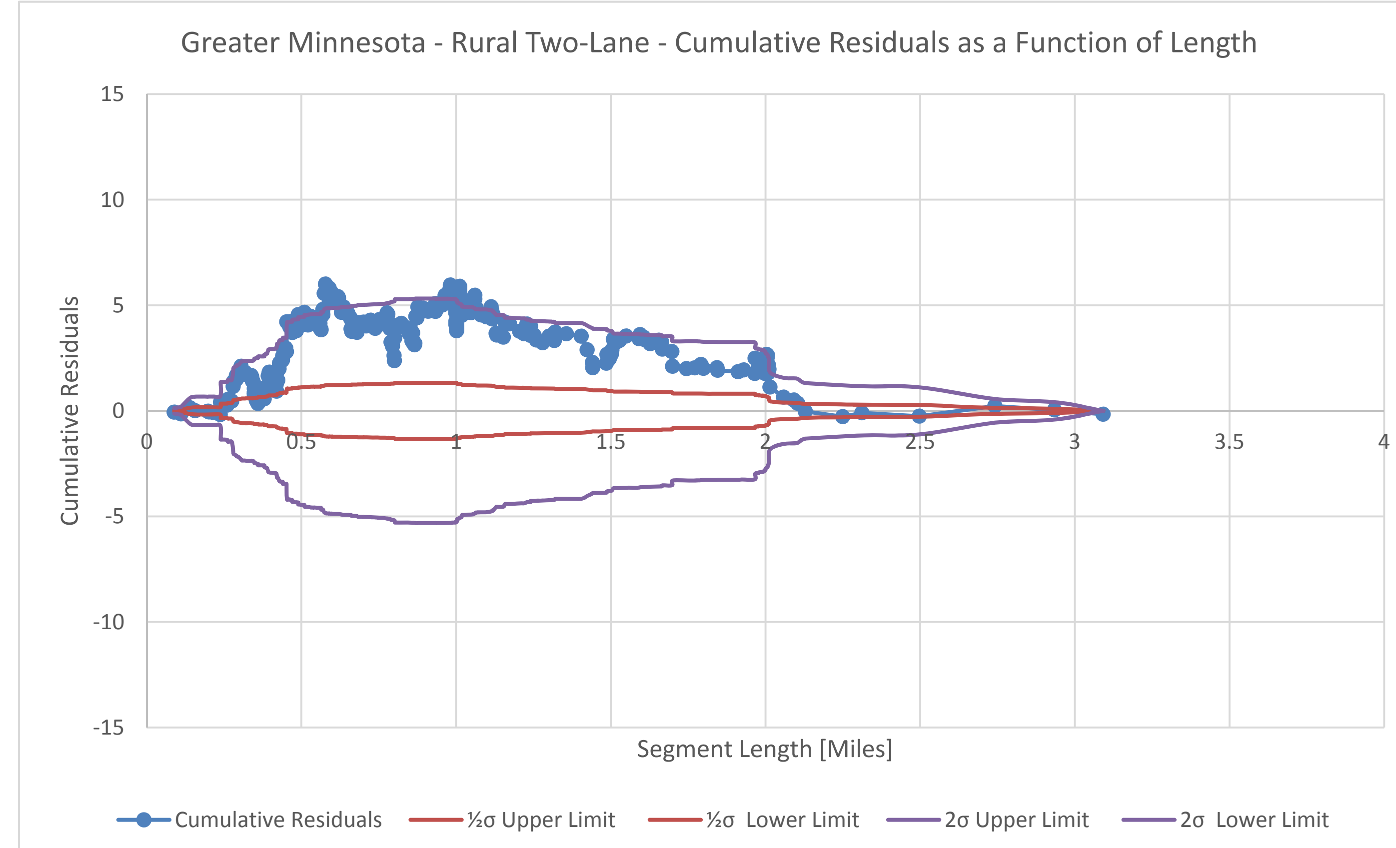
Cumulative Residual (CURE) Plots

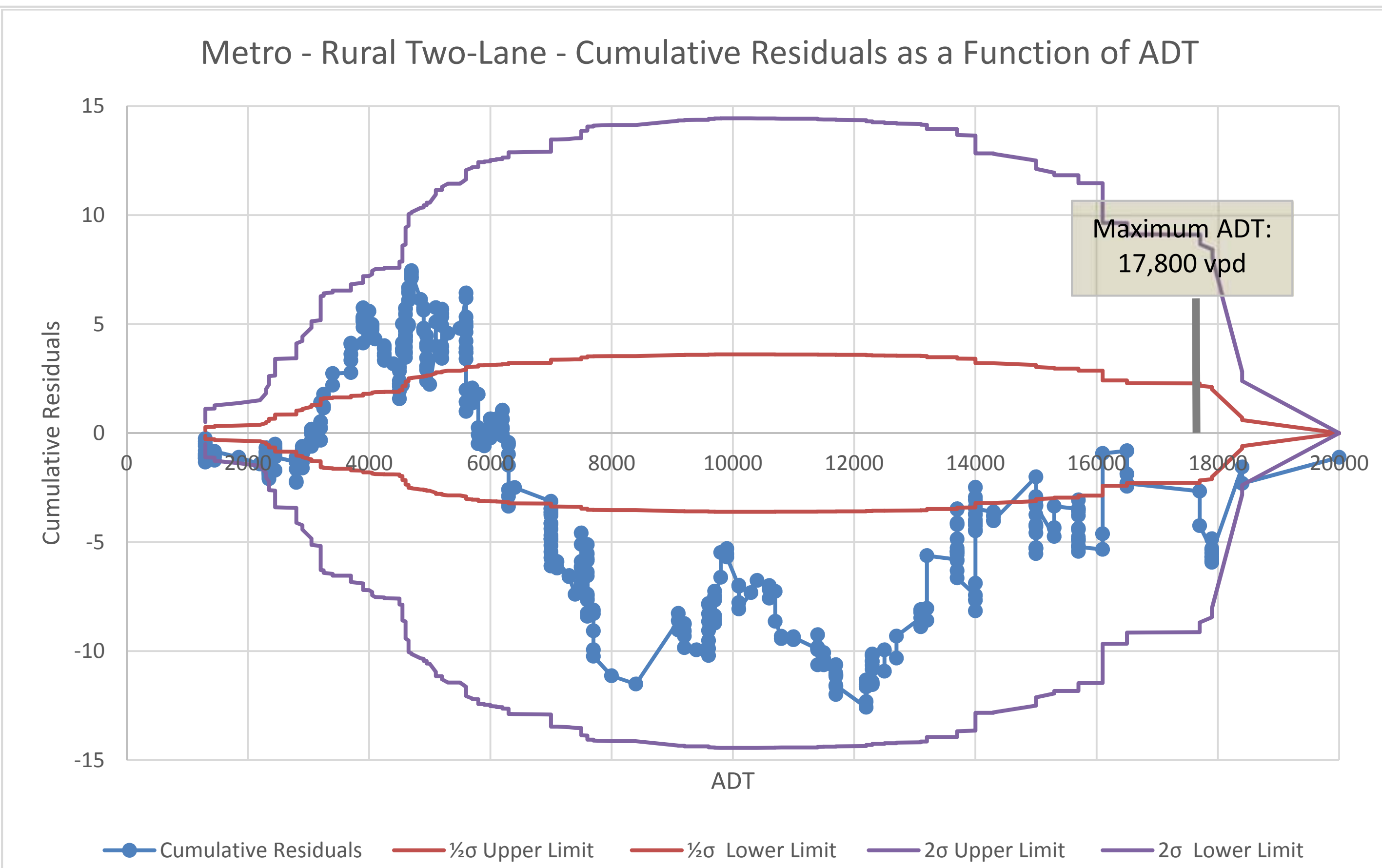
Rural Two-Lane, Two-Way Highways – Roadway Segments

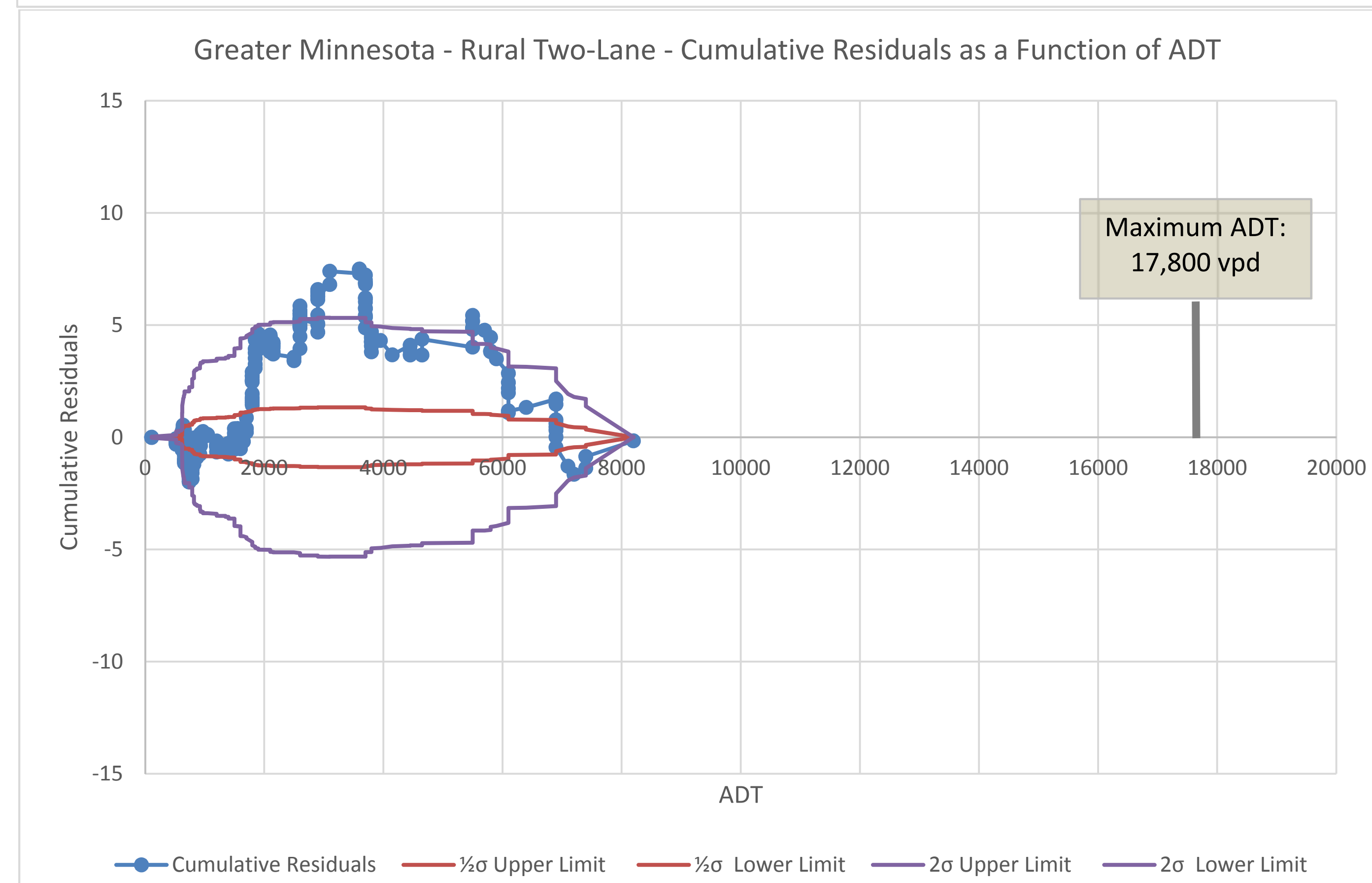
Metro



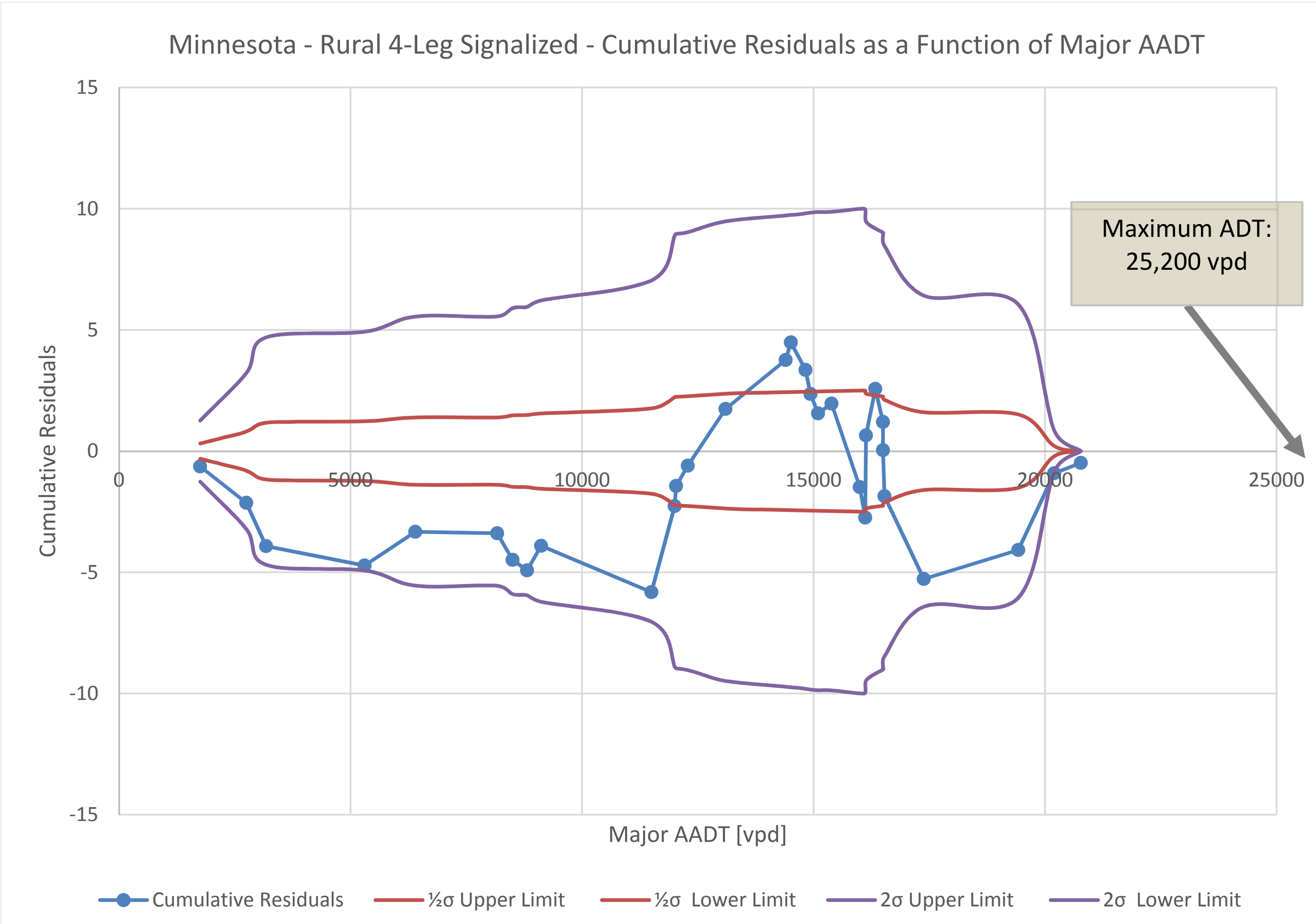
Greater Minnesota

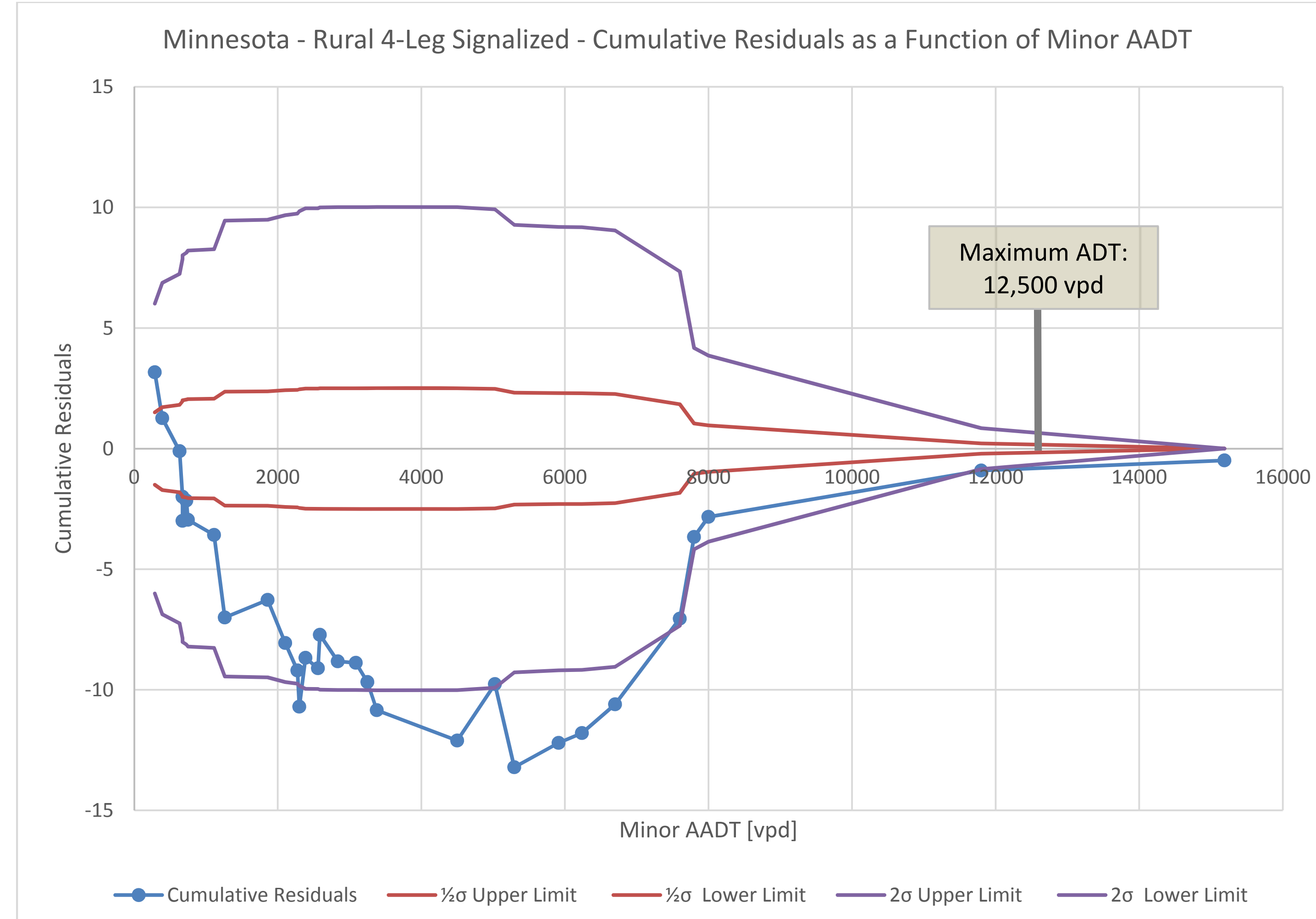






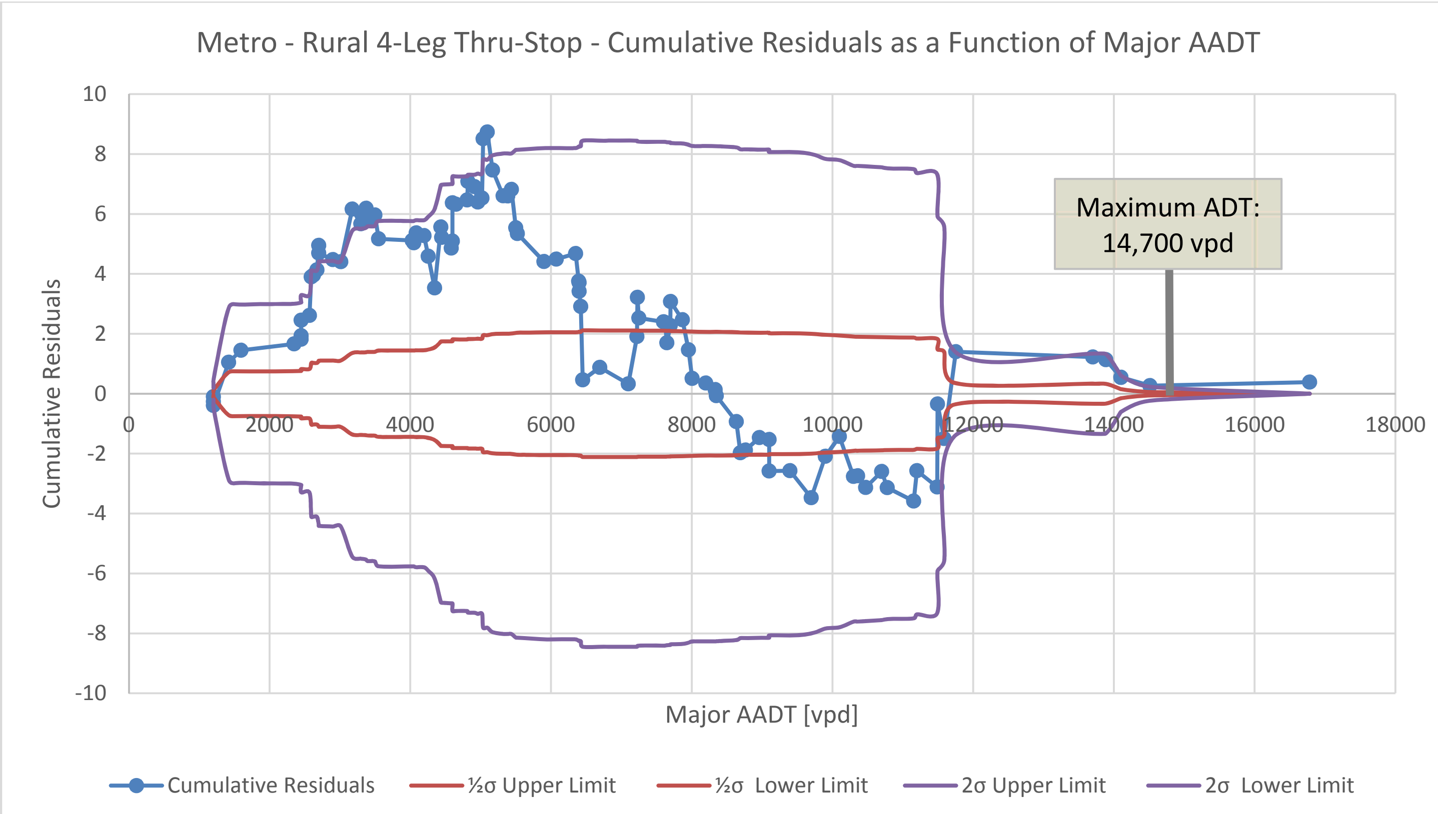
Rural Two-Lane, Two-Way Highways– Four-Leg Signalized Intersections (4SG)

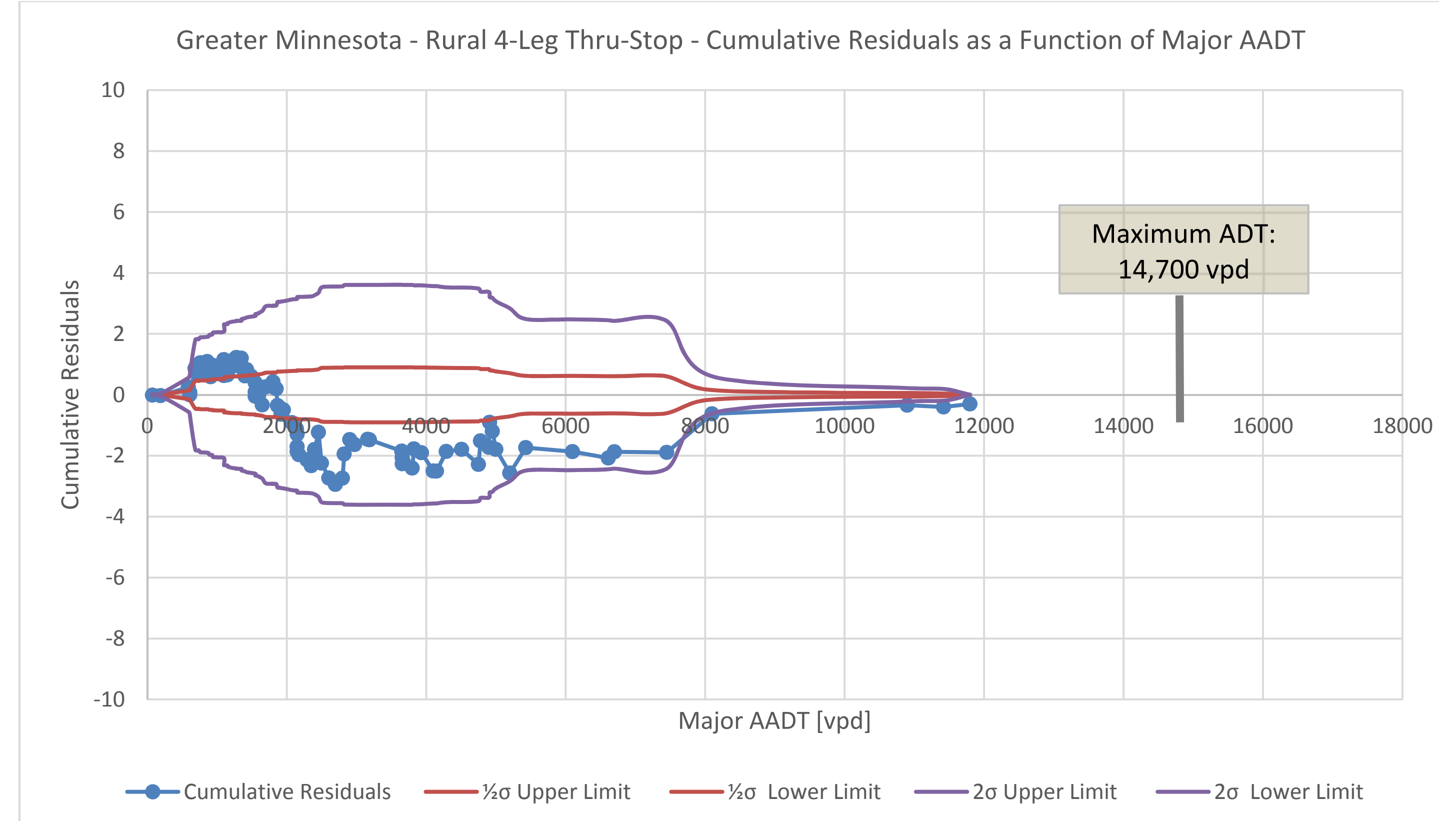


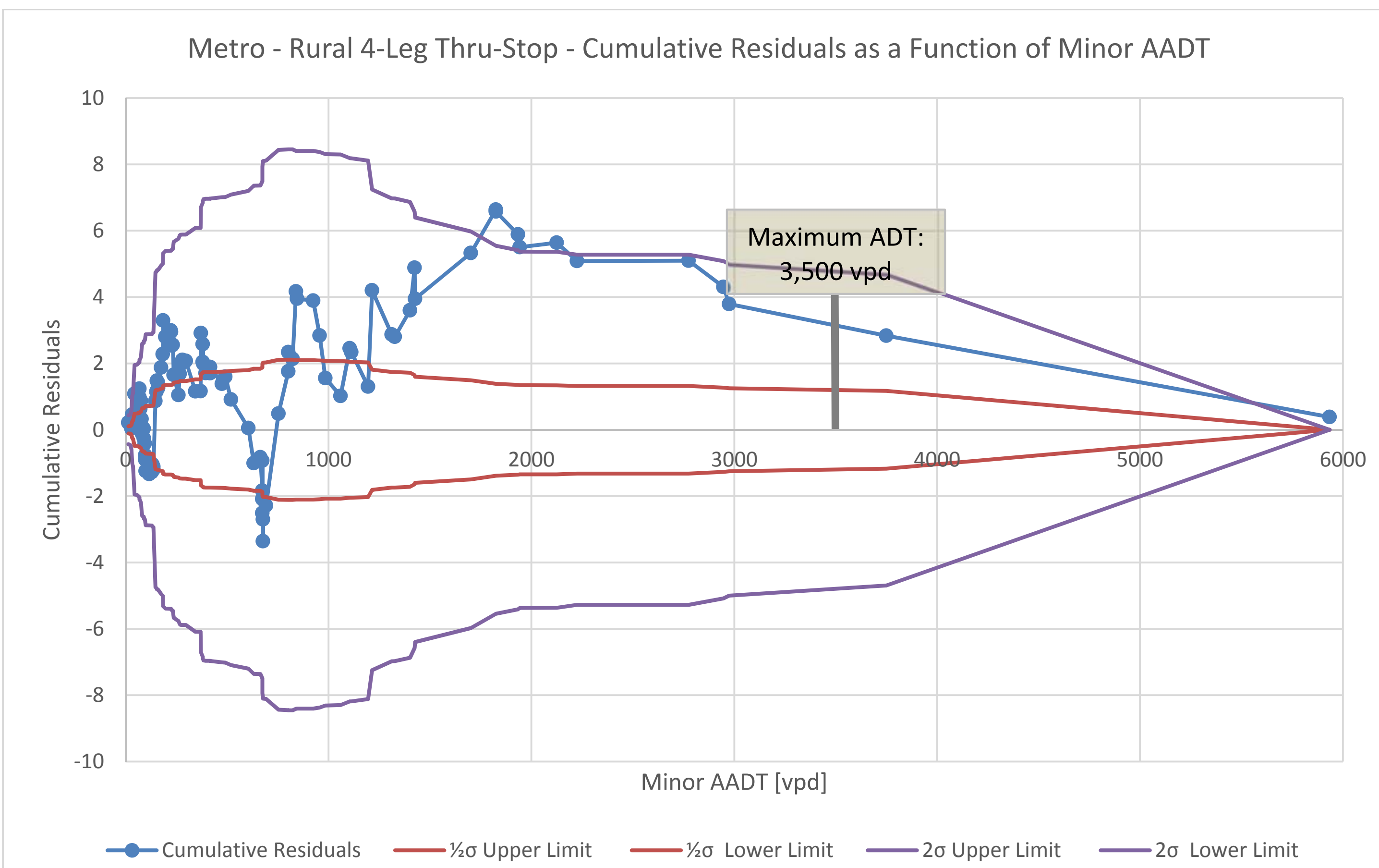


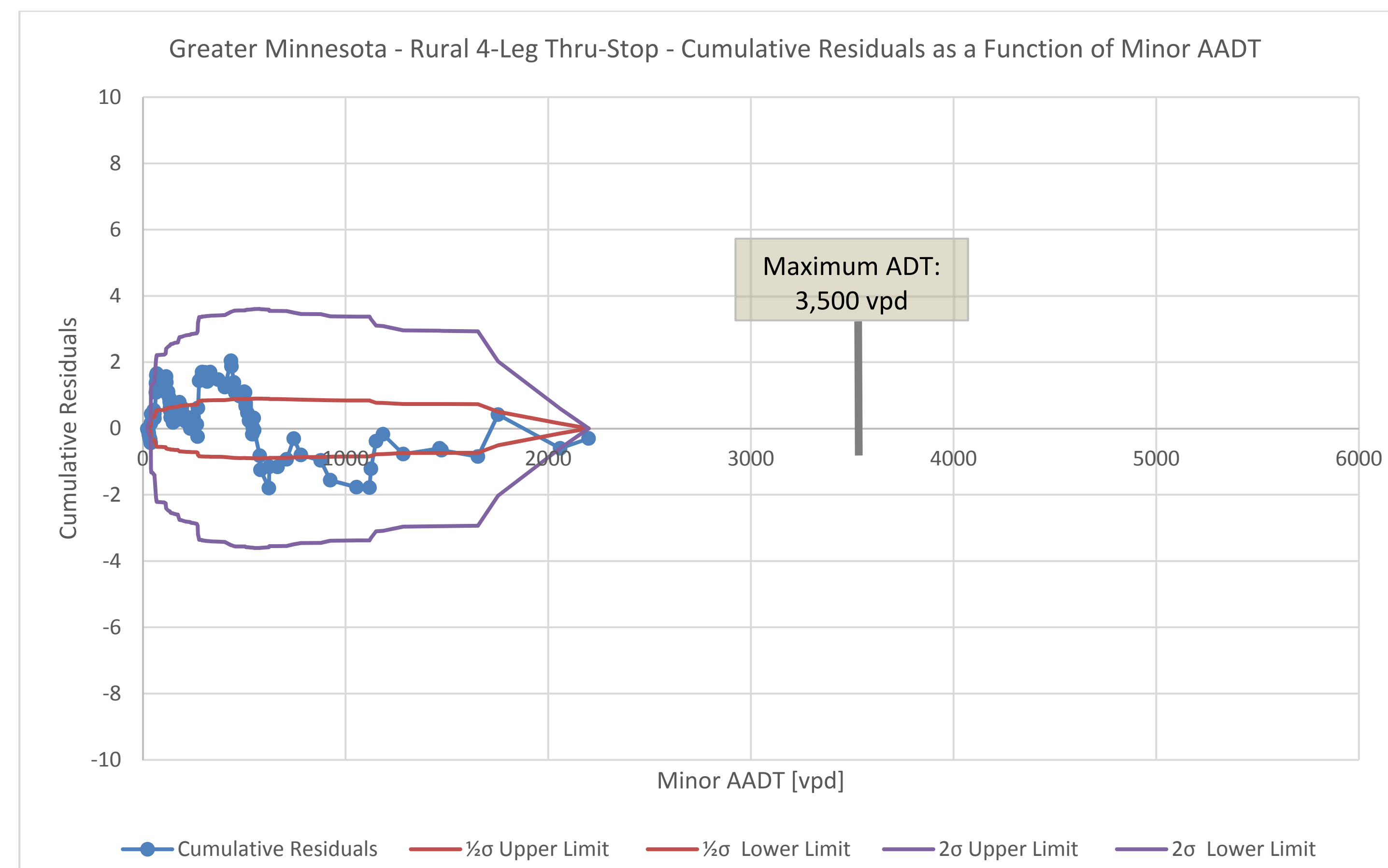
Rural Two-Lane, Two-Way Highways – Four-Leg Thru-Stop Intersections (4ST)

Metro





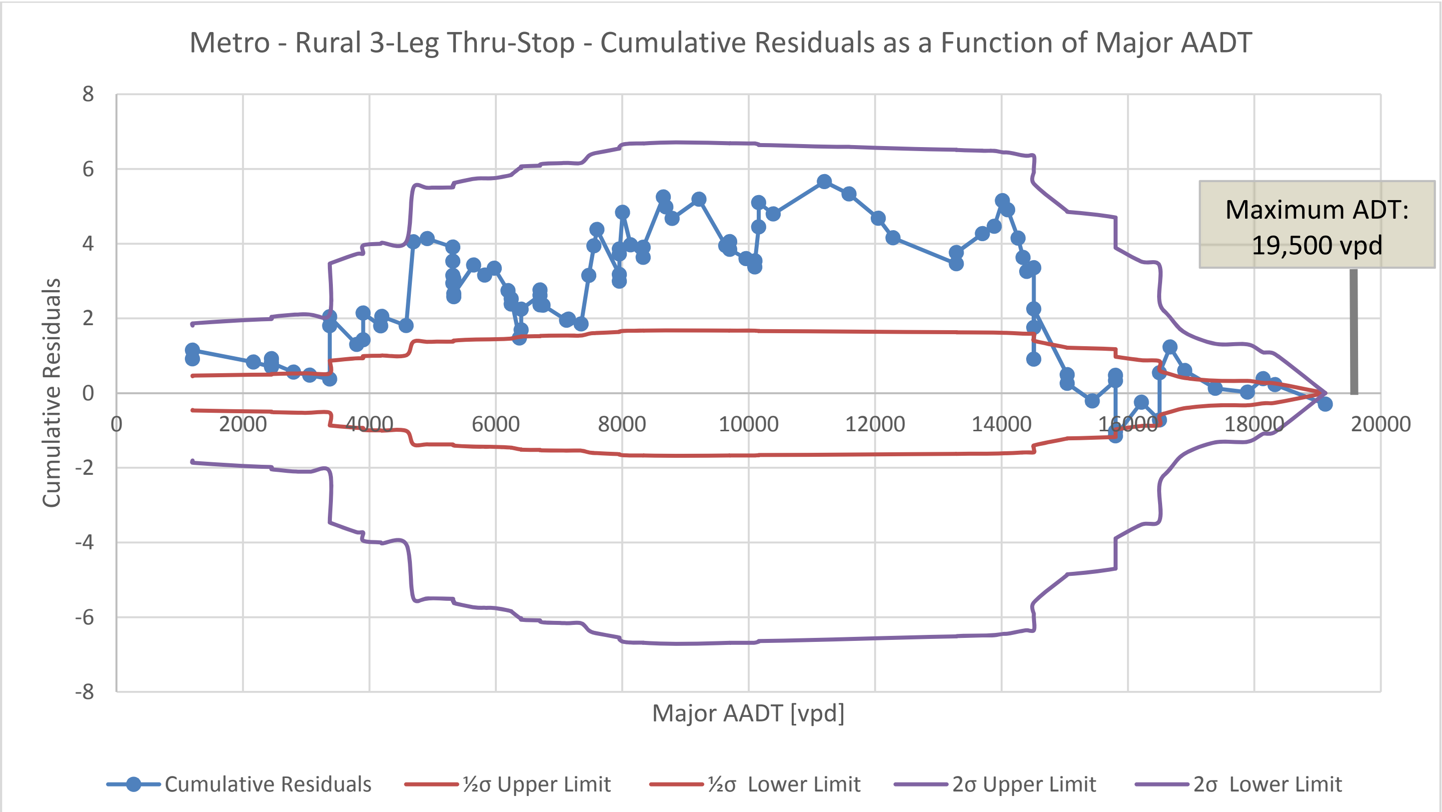




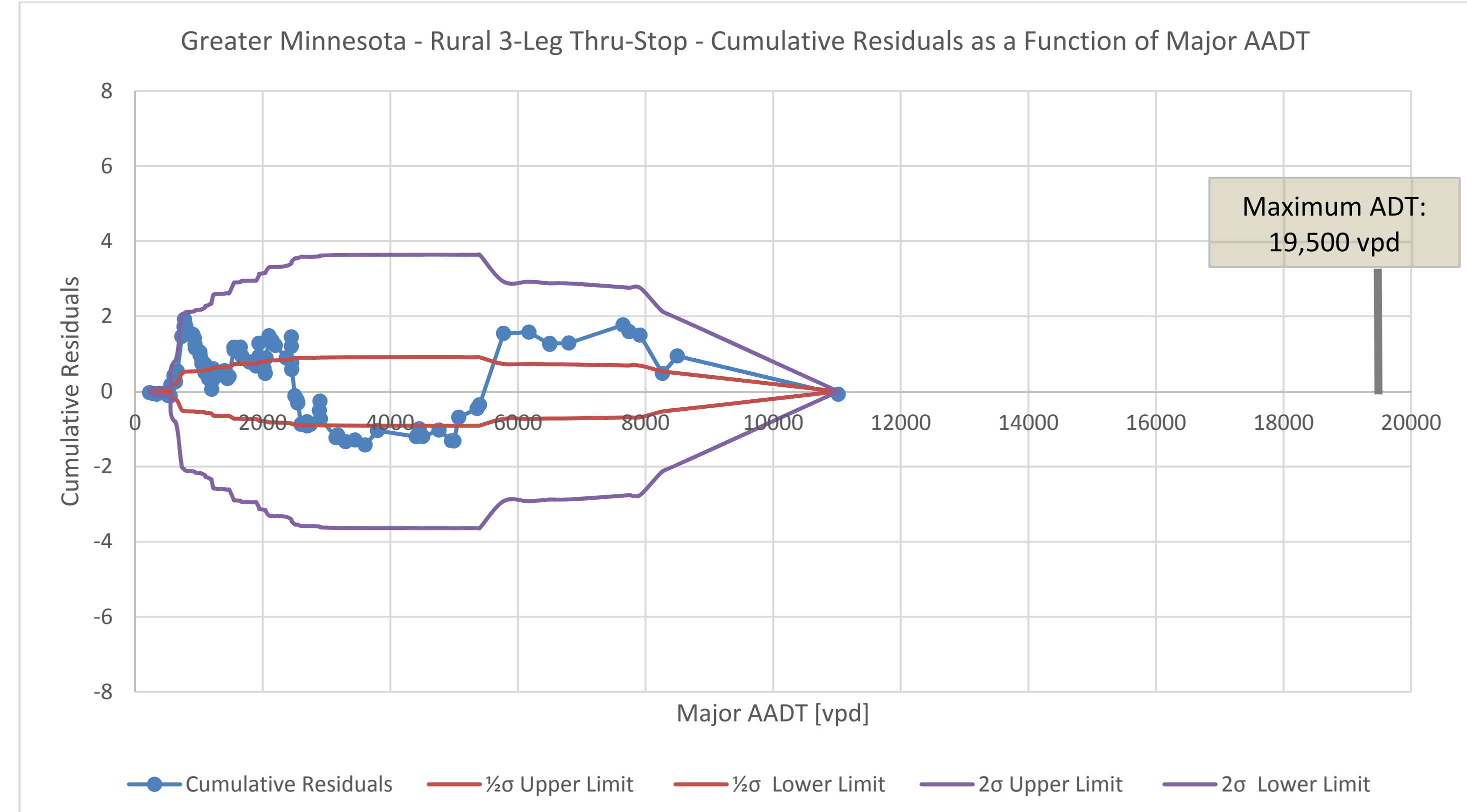
Greater Minnesota

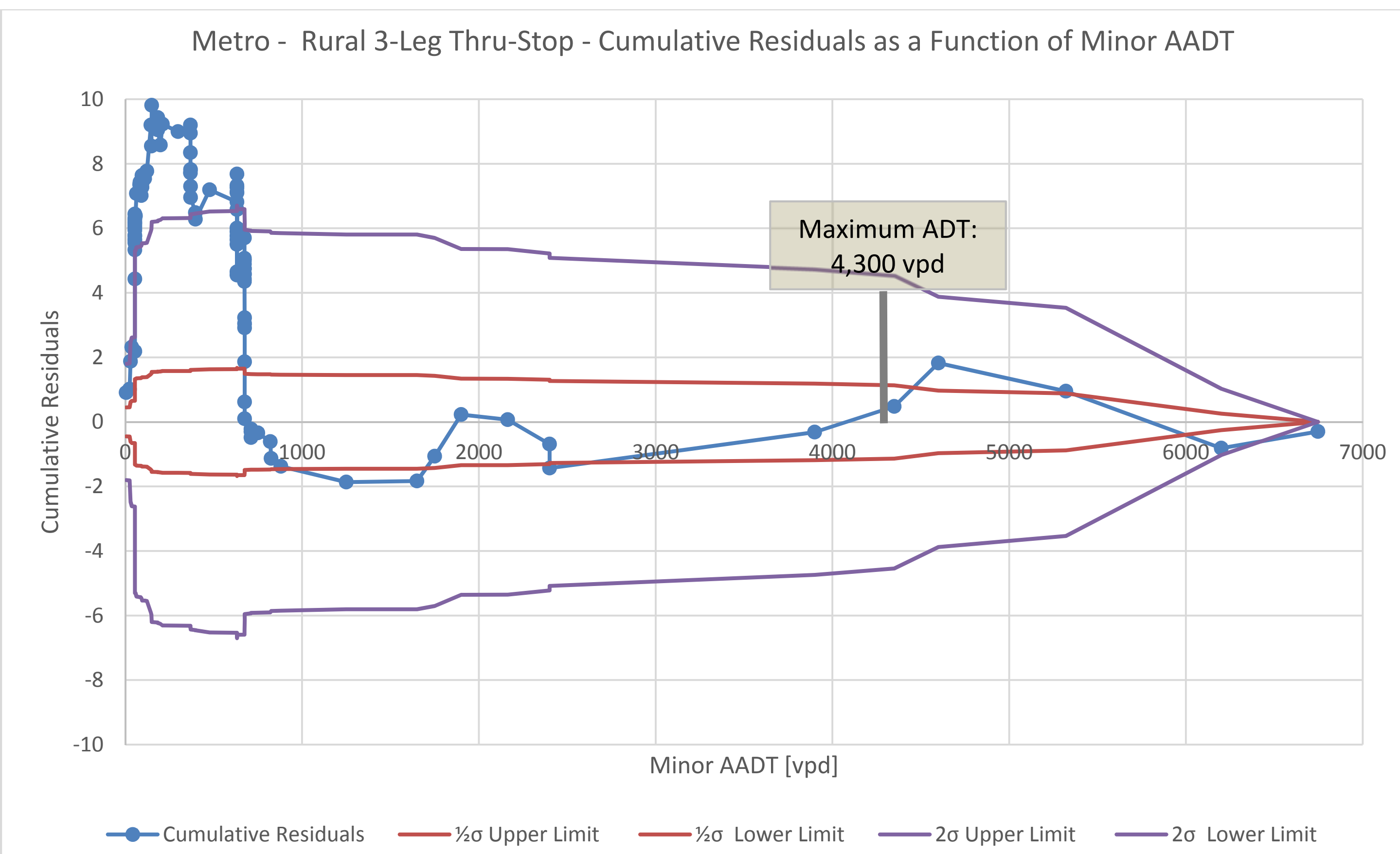
Rural Two-Lane, Two-Way – Three-Leg Thru-Stop Intersections (3ST)

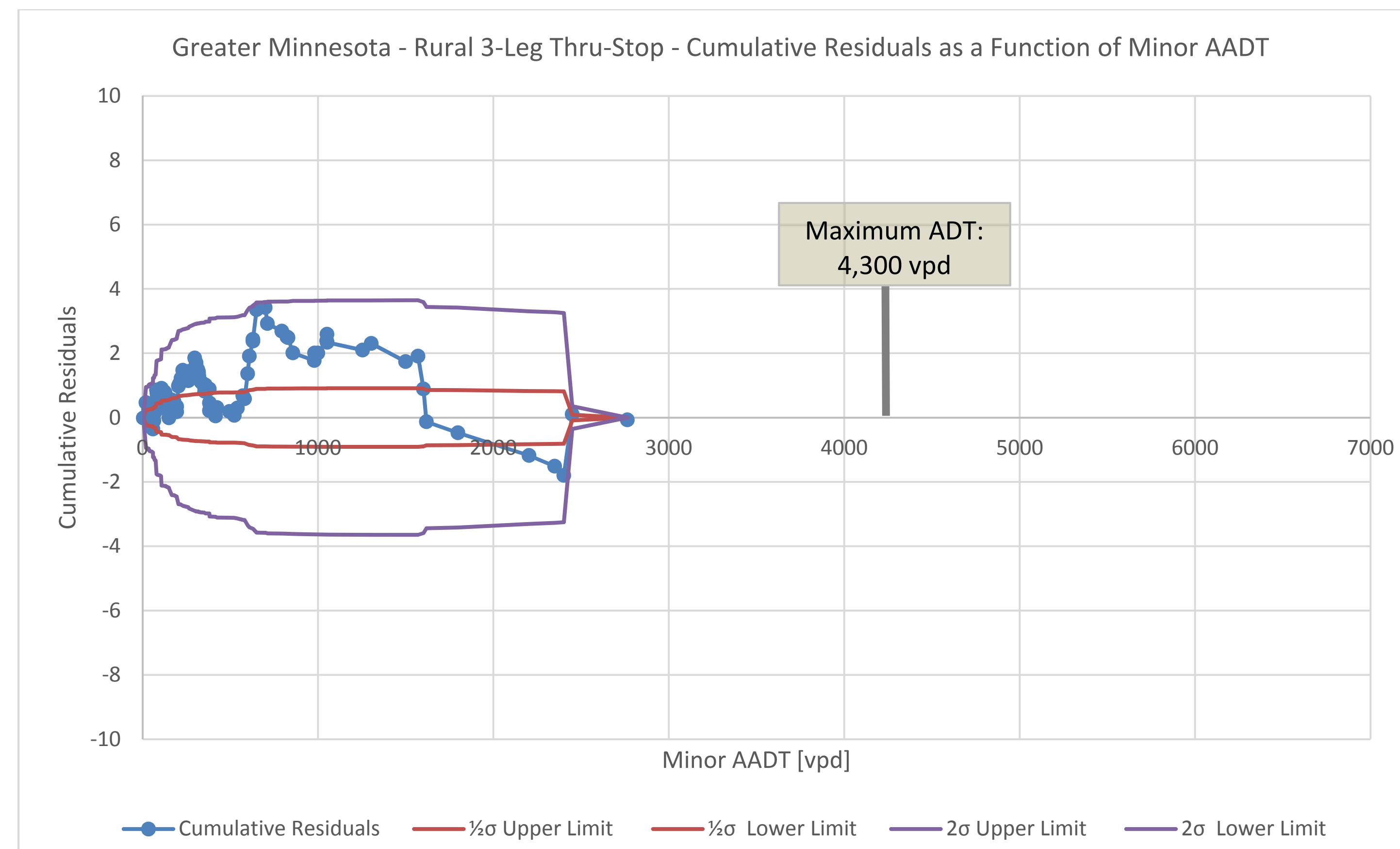
Metro



Greater Minnesota

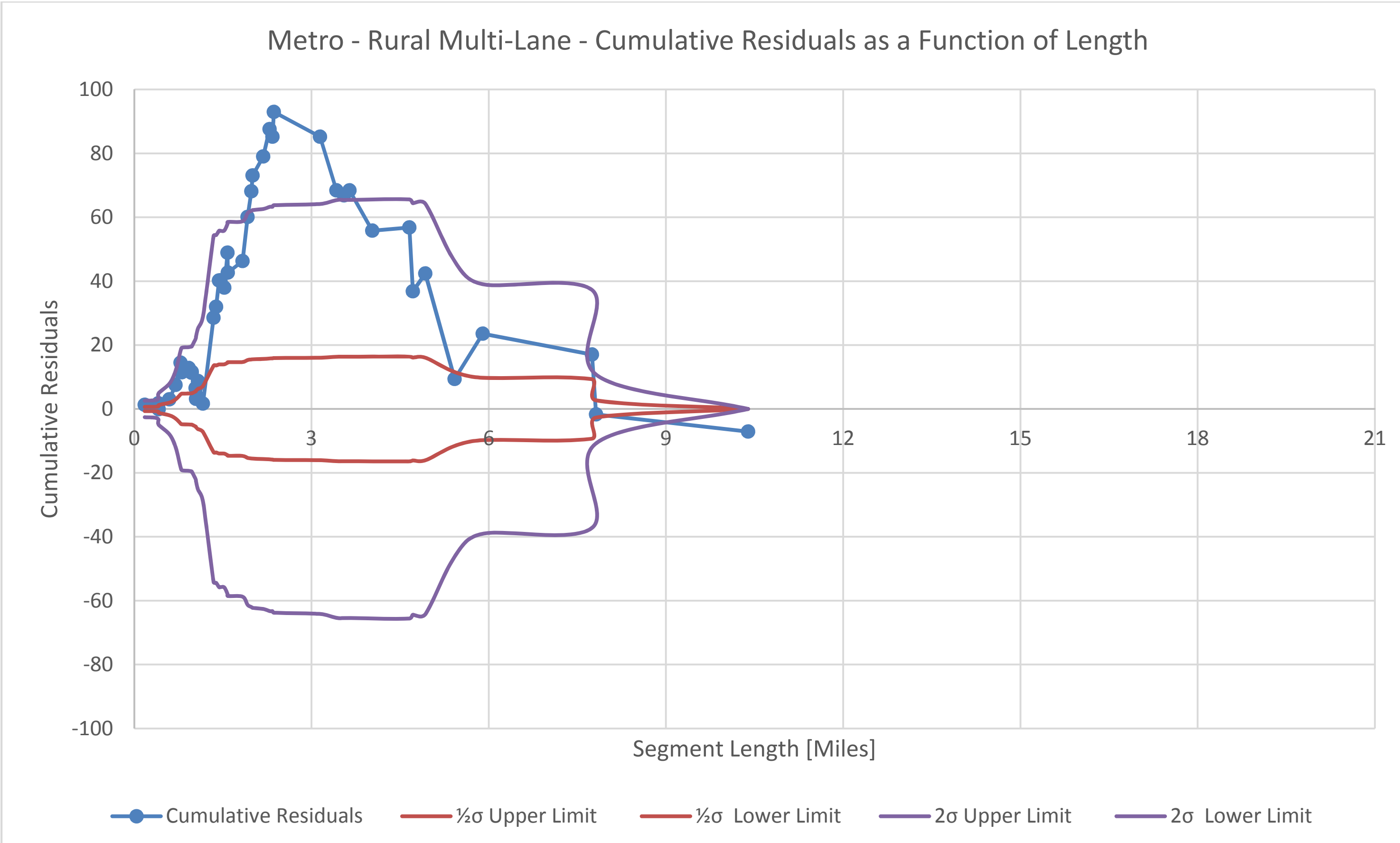


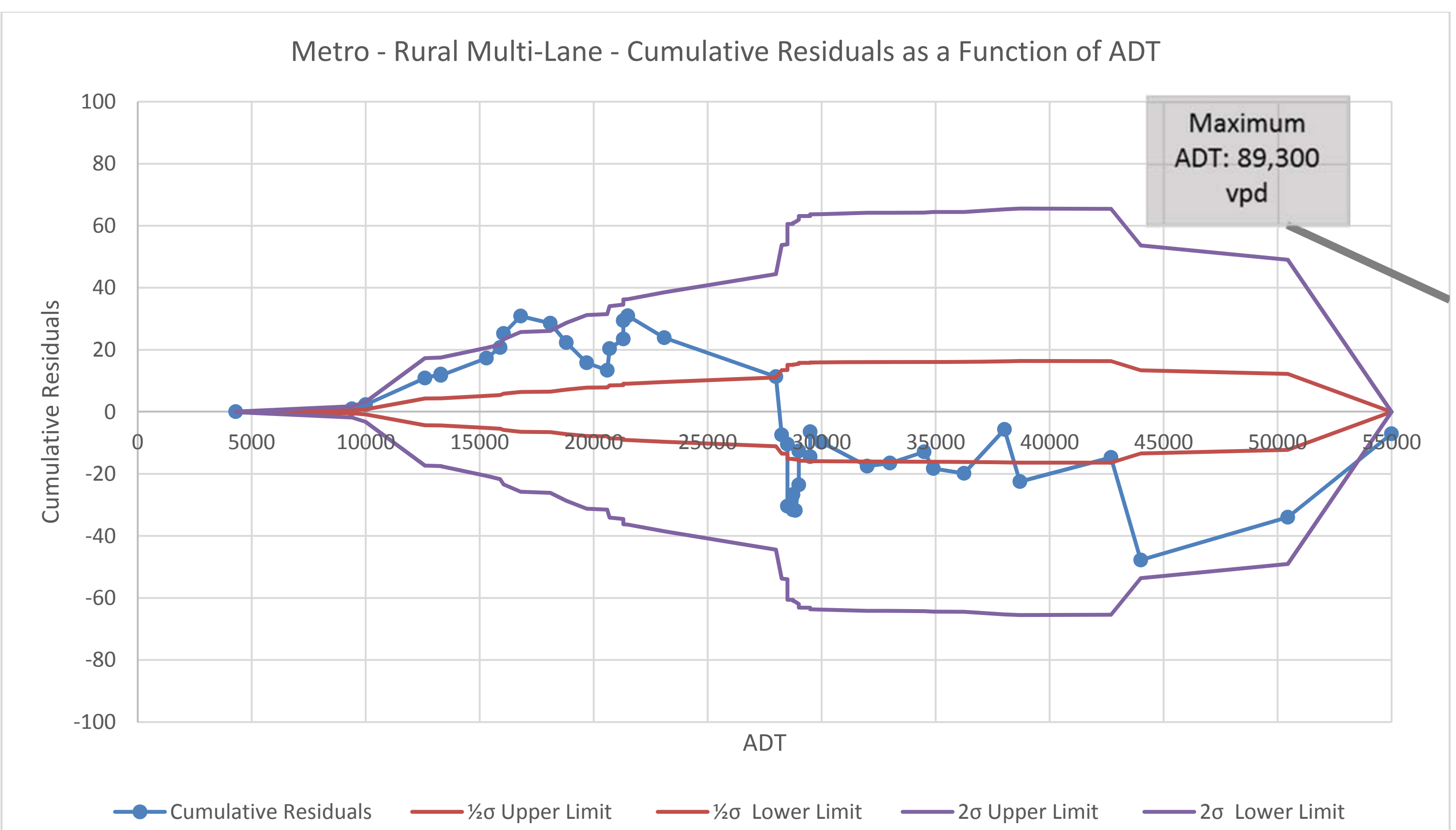




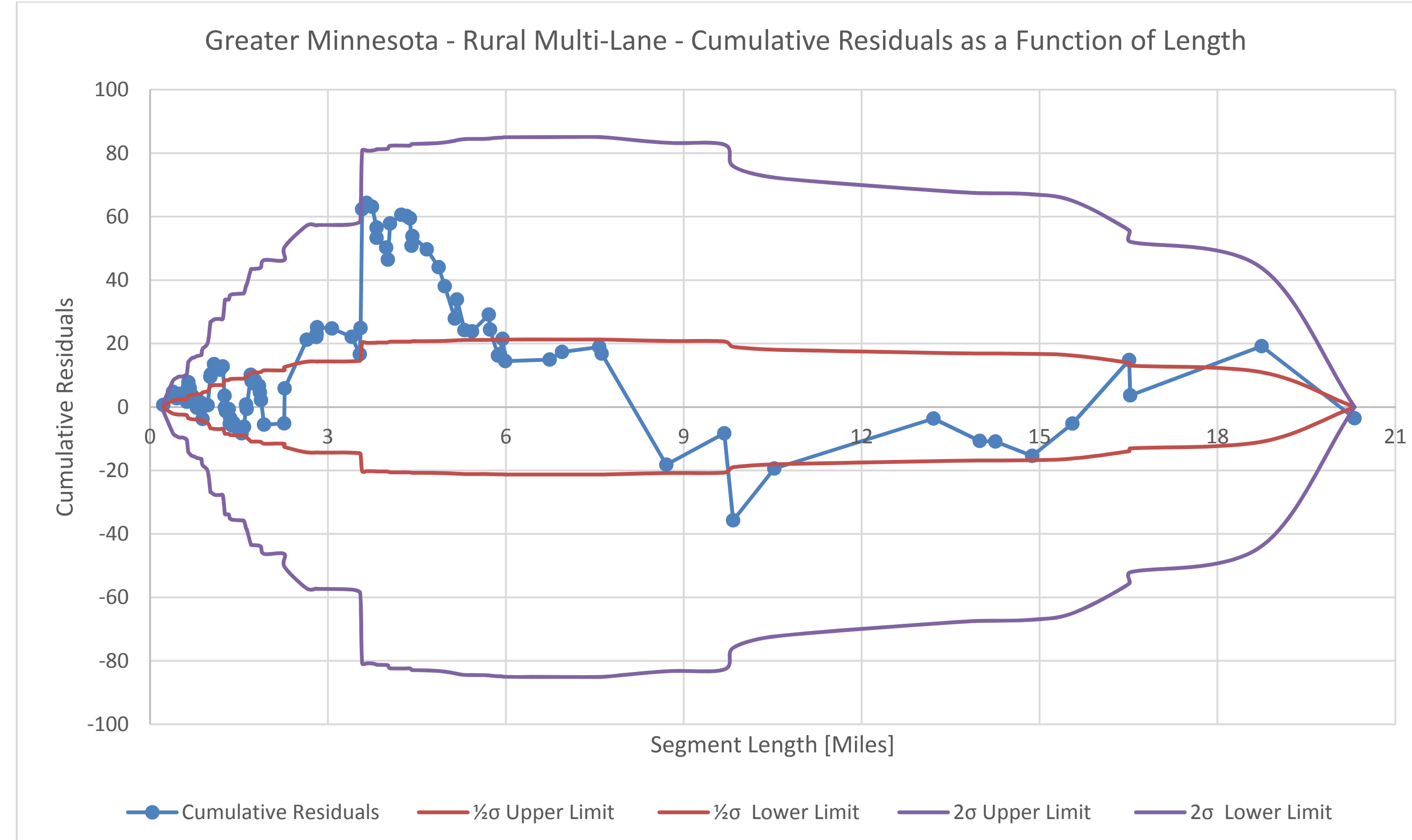
Rural Expressways – Roadway Segments

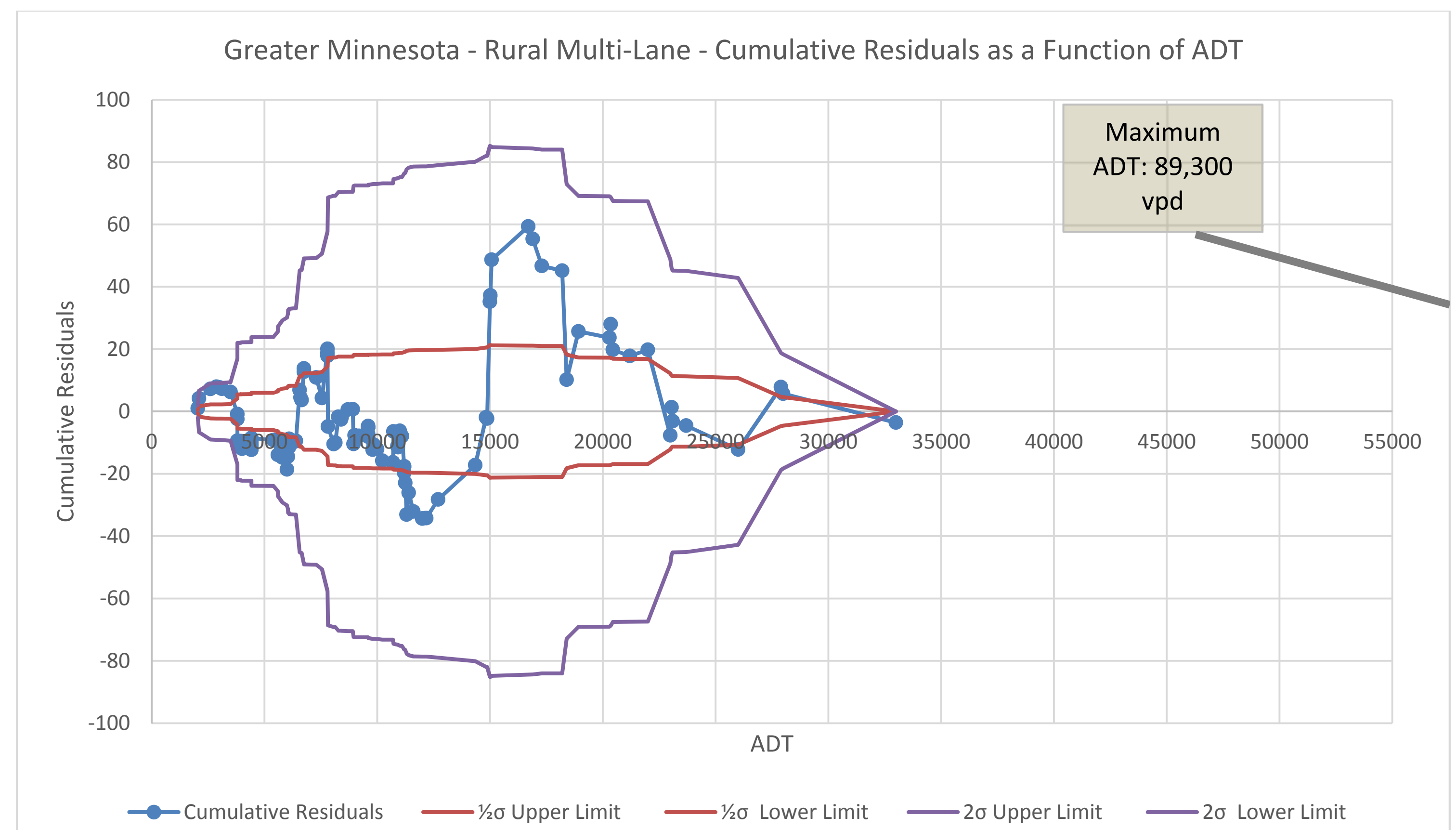
Metro



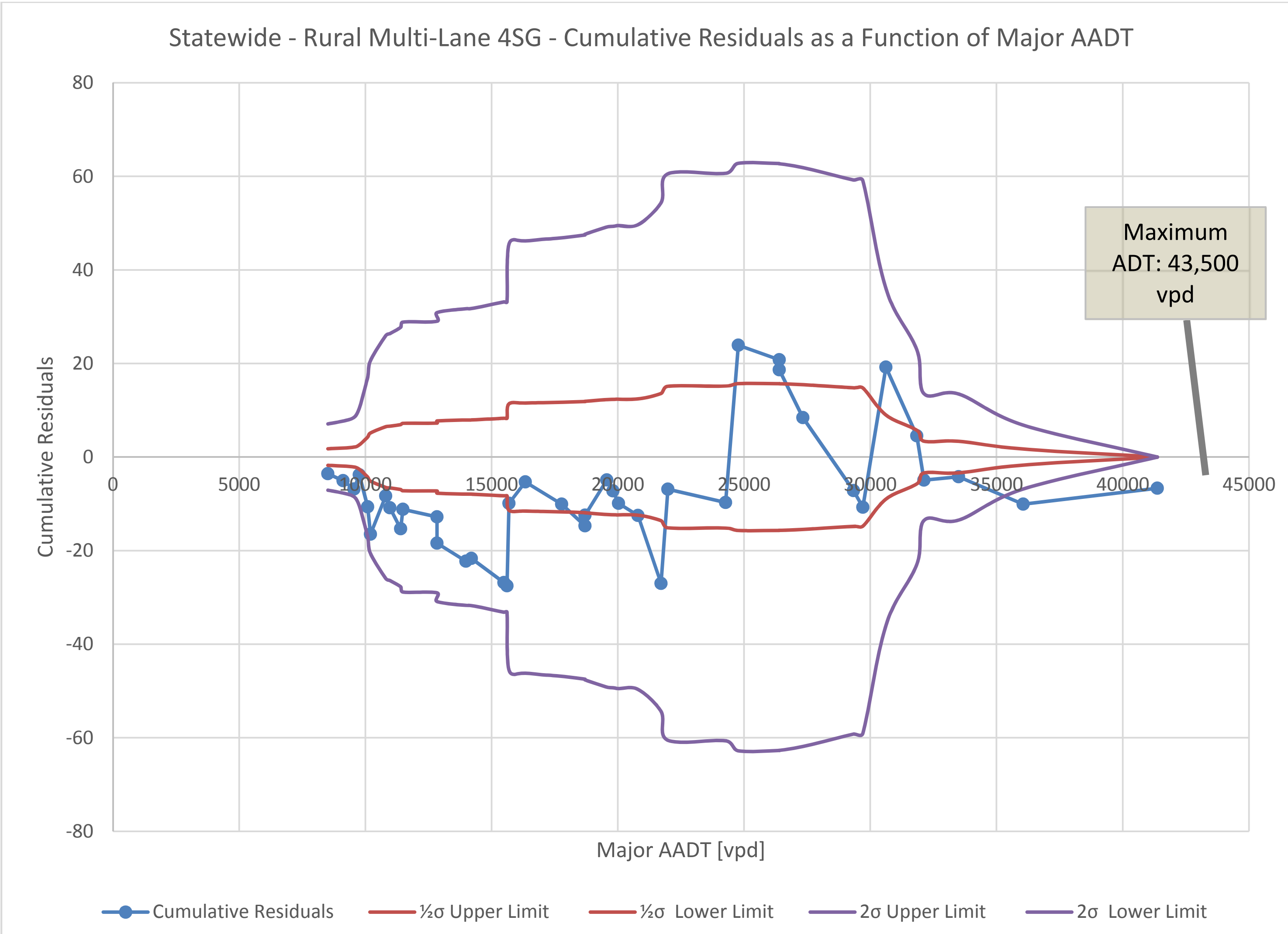


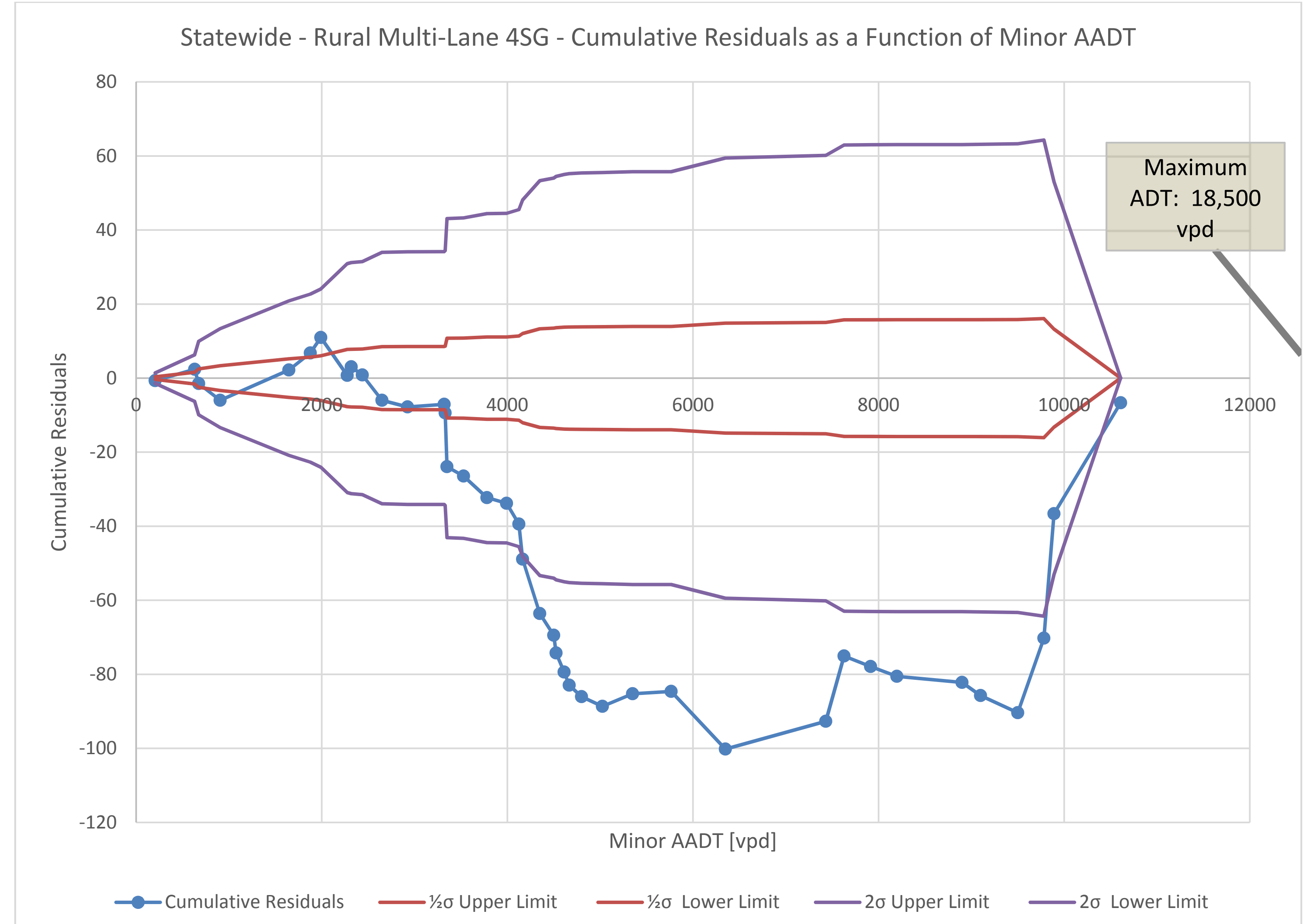
Greater Minnesota





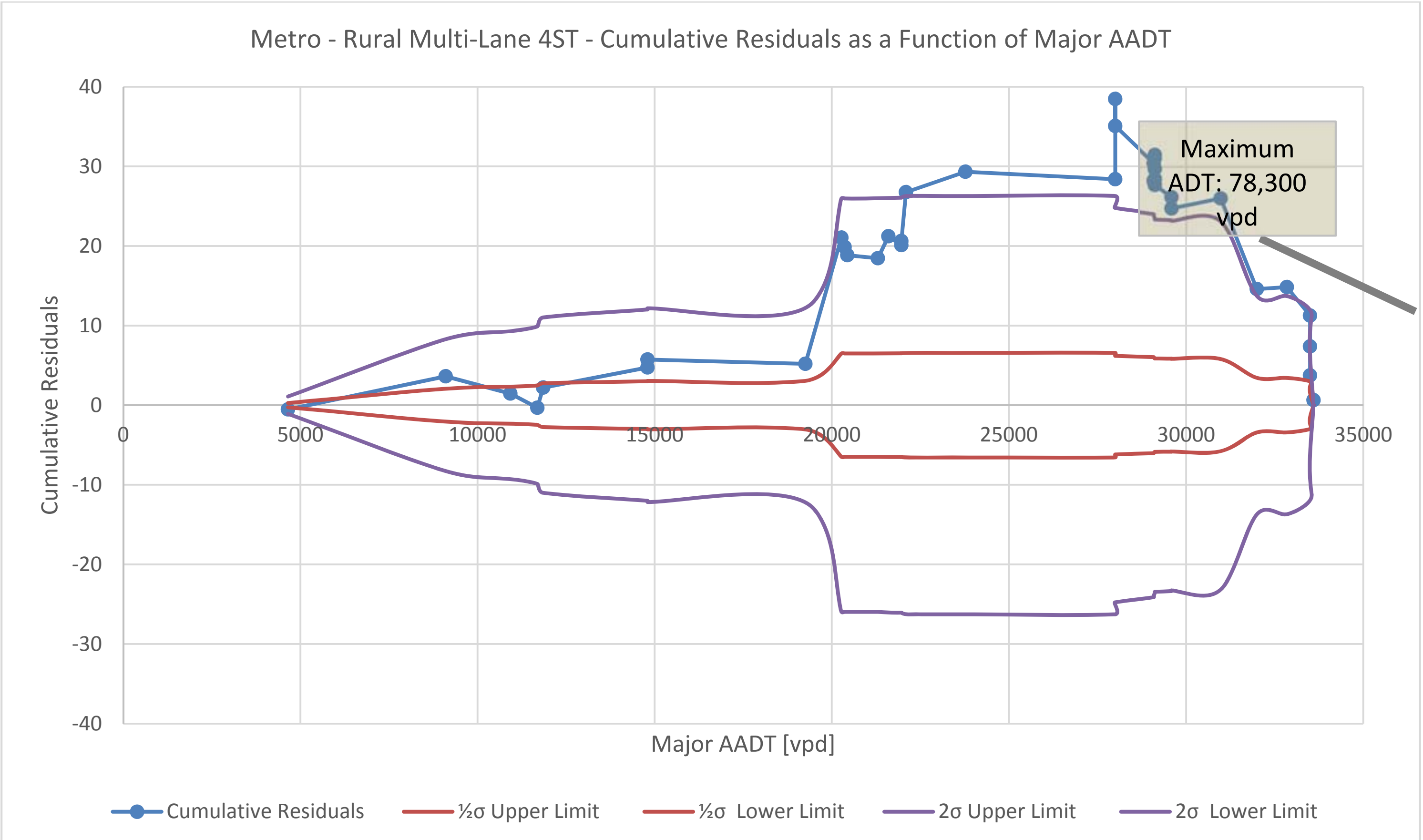
Rural Expressway – Four-Leg Signalized Intersections (4SG)

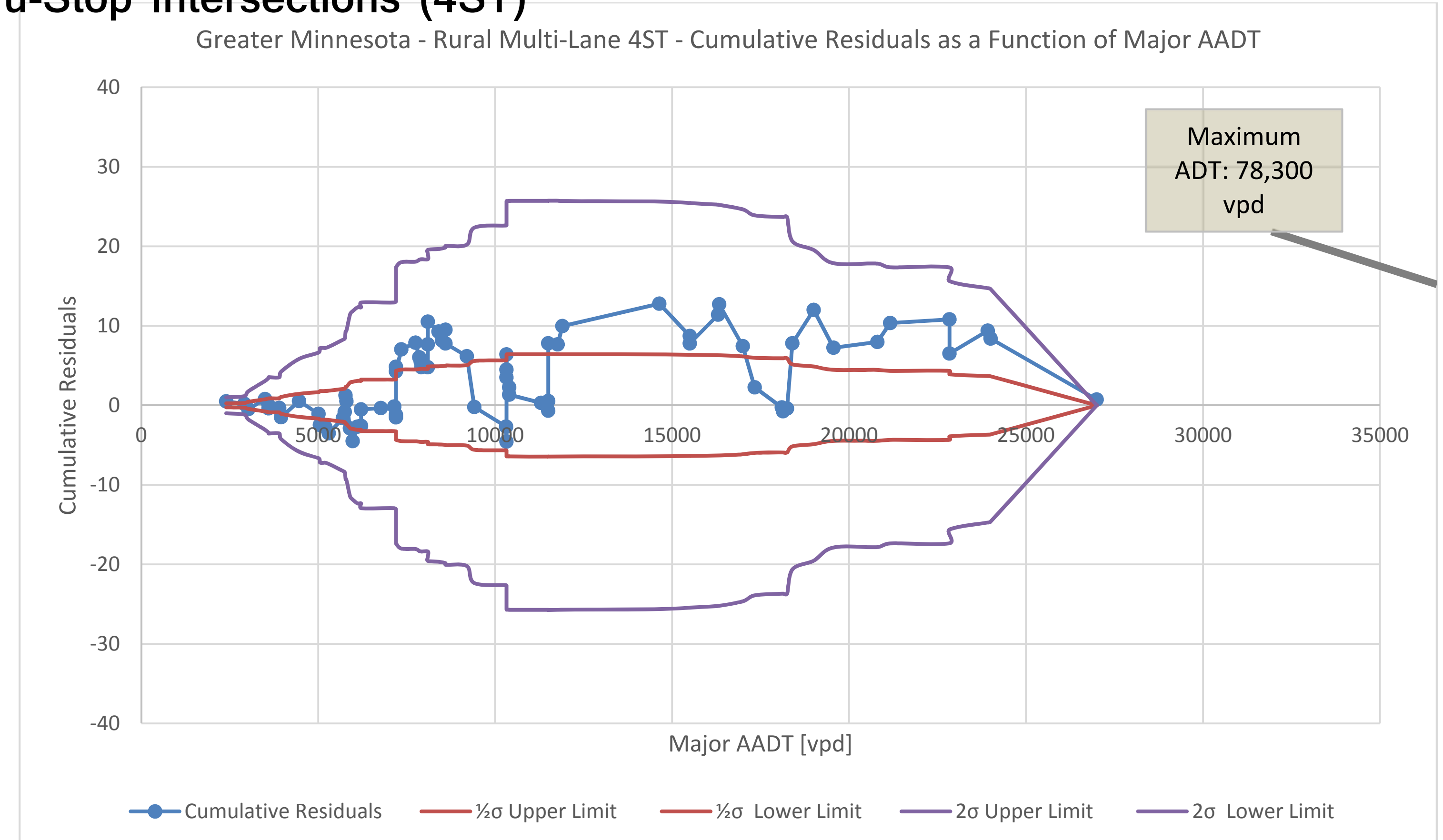


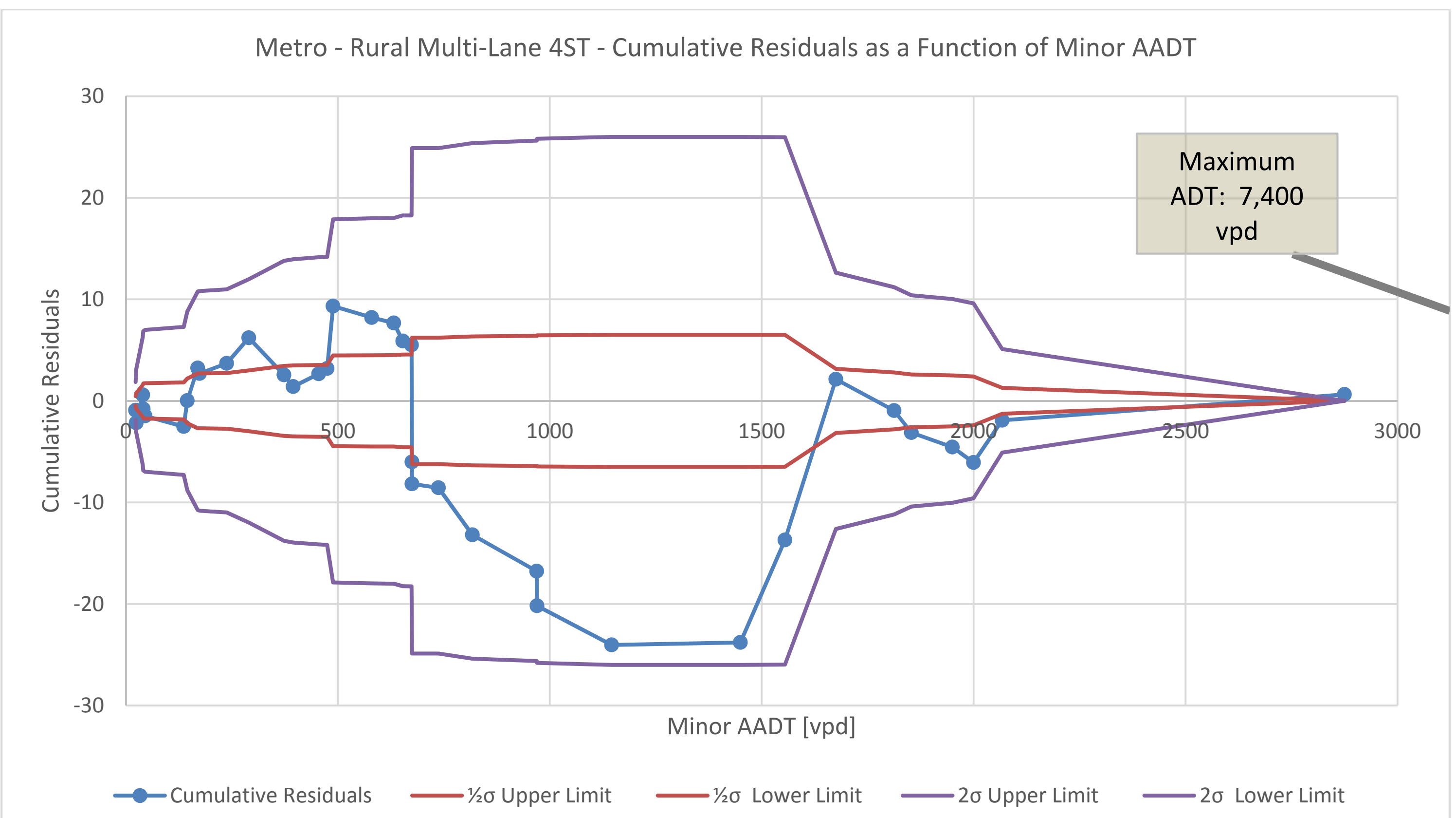


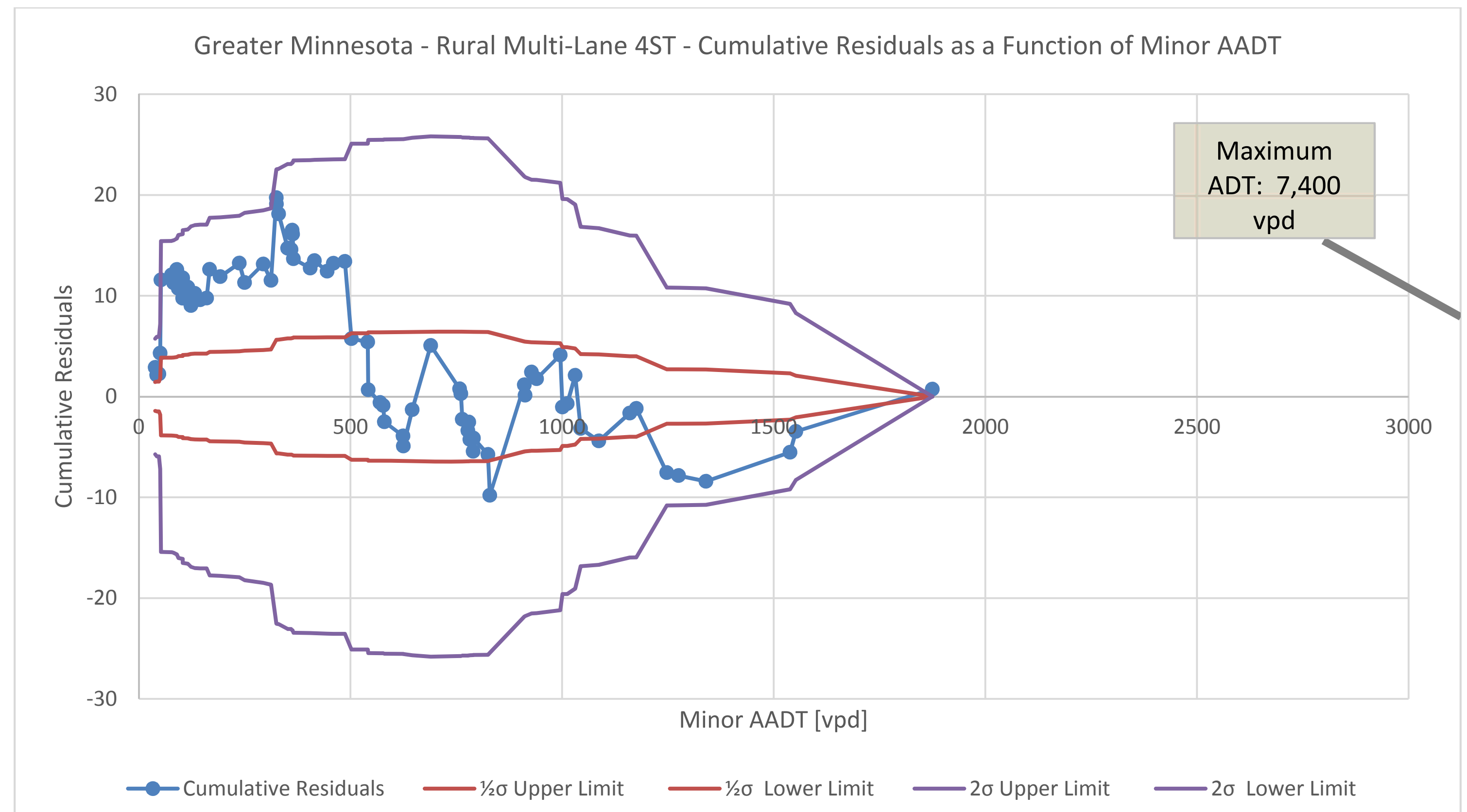
Rural Expressways – Four-Leg Thru-Stop Intersections (4ST)

Metro





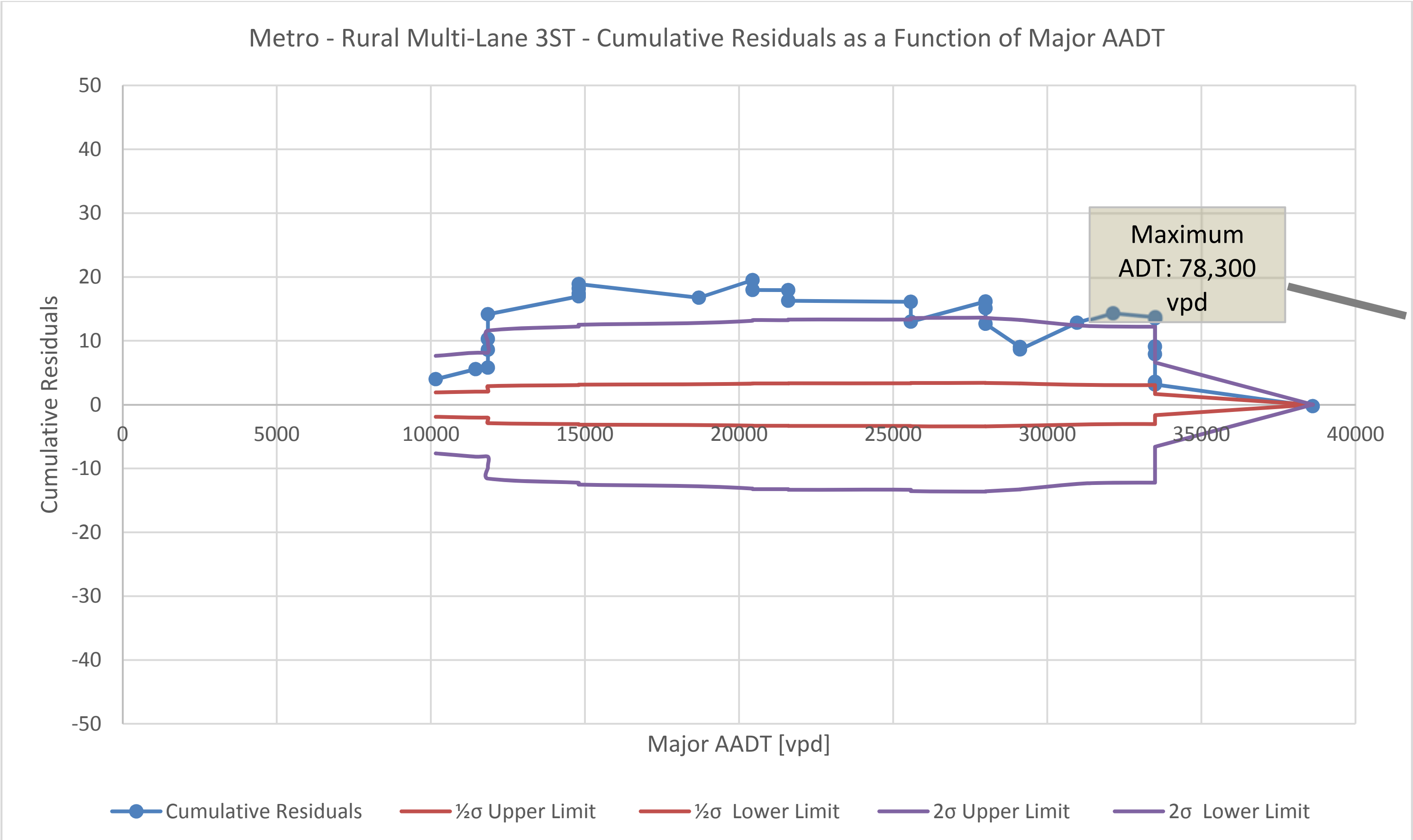




Metro

Greater Minnesota

Rural Expressway – Three-Leg Thru-Stop Intersections (3ST)



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