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SAFETY PERFORMANCE FUNCTIONS FOR INTERSECTIONS

December 2009

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16. Abstract

Road safety management activities include screening the network for sites with a potential for safety improvement (Network Screening), diagnosing safety problems at specific sites, and evaluating the safety effectiveness of implemented countermeasures. It is important that these activities be both efficient and methodologically sound, since resources would otherwise be wasted on unnecessary treatments for safe elements and elements deserving of treatment would be left untreated.

The state-of-the-art methodologies for conducting these activities make use of statistical models to predict expected accident frequencies using traffic volumes and other site characteristics as the input to the models (known as Safety Performance Functions or SPFs). CDOT's research and safety engineers are in the forefront of national efforts to develop methods using SPFs to screen large networks to find sites with a potential for safety improvement.

CDOT has previously developed SPFs to identify freeway and rural roadway segments that have the potential for accident reduction. This report documents the data collection, modeling efforts, and findings of a research project to develop SPFs for ten categories of intersections.

Implementation:

The development of SPFs for ten intersection categories was successful. It is recommended that data for additional sites be collected as they may become available. Additionally, as more years of crash and traffic data become available, these data too can be added to the dataset in order to continually add up-to-date information. The models can be recalibrated to apply to these additional years of data. When several additional years of data are available, it may be desirable to calibrate a new set of original SPFs

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SAFETY PERFORMANCE FUNCTIONS FOR INTERSECTIONS

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1.0 INTRODUCTION

Road safety management activities include screening the network for sites with a potential for safety improvement (Network Screening), diagnosing safety problems at specific sites, and evaluating the safety effectiveness of implemented countermeasures. It is important that these activities be both efficient and methodologically sound, since resources would otherwise be wasted on unnecessary treatments for safe elements and elements deserving of treatment would be left untreated.

The state-of-the-art methodologies for conducting these activities make use of statistical models to predict expected accident frequencies using traffic volumes and other site characteristics as the input to the models (known as Safety Performance Functions or SPFs). CDOT's research and safety engineers are in the forefront of national efforts to develop methods using SPFs to screen large networks to find sites with a potential for safety improvement.

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The following is an example of an SPF for an intersection:

$$\text{Accidents/year} = (\text{alpha})\cdot(\text{AADTmaj})^{b1}\cdot(\text{AADTmin})^{b2}$$

where,

- alpha, b1 and b2 are parameters estimated in the modeling process;
- AADTmaj and AADTmin are the estimated average annual daily traffic volumes on the major and minor roads, respectively.

It was unfeasible to collect data for all intersections under CDOT's jurisdiction due to budget constraints. The intersection categories pursued for this project were determined after considering the number of locations and the availability of existing minor road traffic counts. Staff from CDOT was also consulted to ensure intersection categories were included that are of high priority for CDOT. Following this evaluation, the analysis team developed a plan to select a random sample of sites for further data collection, keeping in mind that locations throughout Colorado geographically must be represented as well as a range of traffic volumes and other variables. Without such a diverse representation, the SPFs will not be applicable across the state and for the spectrum of pertinent variables.

Data were collected for ten categories of intersections using information from intersections on CDOT maintained roadways. SPFs were developed separately for Total and Injury (fatal+injury) accidents. These ten intersection categories include:

1. Urban 4-Lane Divided Signalized 4-Leg
2. Urban 6-Lane Divided Signalized 4-Leg
3. Urban 4-Lane Divided Signalized 3-Leg
4. Urban 2-Lane Undivided Unsignalized 4-Leg
5. Urban 4-Lane Divided Unsignalized 4-Leg
6. Urban 2-Lane Undivided Unsignalized 3-Leg
7. Urban 4-Lane Divided Unsignalized 3-Leg
8. Urban 4-Lane Undivided Unsignalized 4-Leg
9. Urban 2-Lane Divided Unsignalized 3-Leg
10. Urban 4-Lane Undivided Unsignalized 3-Leg

Where,

Urban	=	Area characteristic
X-Lane	=	Total number of through lanes on mainline State highway
Divided/ Undivided	=	Specifies whether any separation exists between the primary and secondary travel lanes. If a median or left-turn lane is present, a roadway is considered Divided.
Signalized/ Unsignalized	=	Traffic control at intersections is either a traffic signal or stop-sign controlled
X-Leg	=	Specifies whether the intersection has 4 approaches or 3 approaches (a “Tee” intersection)

2.0 DATA ASSEMBLY

The data collection phase of the project involved two tasks: 1) compiling the mainline AADT and accident count over the study period into a consistent format and 2) collecting sidestreet AADT data and normalizing it to the study period.

The study period was selected solely based on the availability of data. A minimum of five-years of accident data from 2000 through 2004 was collected for each of the ten intersection categories. As the study progressed, some 2005 accident data became available and was used as additional data for intersections as appropriate. For simplicity, this report refers to the period of accident data collection as the "study period" without explicitly stating whether five or six years of data were used.

The accident data and mainline AADT volumes were provided by CDOT's Safety Engineering and Analysis group, which maintain a comprehensive set of databases containing detailed accident history as well as geometric data. The intersections were initially identified using the Colorado Roadway Information System (CORIS) database, which contains point location descriptions, laneage and other pertinent details. The intersections were sorted into the appropriate categories and reviewed to ensure the CORIS data matched the in-situ intersection geometry. The resulting lists were used to extract and compile the accident history and mainline AADT for each intersection over the study period.

Existing side-street AADT data were acquired from various readily available sources such as GIS data layers or other already completed traffic counts. These data were then supplemented with traffic counts completed in the field by All Traffic Data Services, Inc. Side-street AADT counts were not generally available for more than one or two years, and in many cases the count data did not coincide with the study period. Thus, it was necessary to normalize the collected side-street AADT data over the study period using growth rates derived from the mainline AADT volumes provided by CDOT.

Resource constraints prohibited collecting data for all locations in Colorado. Thus, data for a sub sample were collected. To avoid biasing the developed models in the site selection process, the analysis team selected a random sample of sites for further data collection, keeping in mind that geographic regions throughout Colorado must be represented as well as a range of traffic volumes. Without such a diverse representation, the SPFs developed would not be applicable across the state and across the range of traffic volumes. The number of sites in the sample was determined considering both the cost of data collection and the analysis costs.

Data collection efforts primarily focused on collecting traffic volume data on the minor street approaches. For some of these locations (approximately 200 intersections), minor road traffic volumes were already available from CDOT. Local jurisdictions were also queried to determine if minor road traffic volumes were available from their records. Field traffic counts on the minor street approaches were conducted at over 150 locations by All Traffic Data Services Inc. **Table 1** summarizes the traffic volume data collected by source.

Table 1 Summary of Data Collection

ID	Full Description	Readily Available[1]	Traffic Counts	Analysis Intersections	Total Crashes
1	Urban 4-Lane Divided Signalized 4-Leg	101	0	101	7,704
2	Urban 6-Lane Divided Signalized 4-Leg	31	15	46	6,092
3	Urban 4-Lane Divided Signalized 3-Leg	11	23	34	1,378
4	Urban 2-Lane Undivided Unsignalized 4-Leg	16	31	47	153
5	Urban 4-Lane Divided Unsignalized 4-Leg	17	32	49	880
6	Urban 2-Lane Undivided Unsignalized 3-Leg	17	17	34	142
7	Urban 4-Lane Divided Unsignalized 3-Leg	9	36	45	397
8	Urban 4-Lane Undivided Unsignalized 4-Leg	4	53	57	207
9	Urban 2-Lane Divided Unsignalized 3-Leg	5	73	78	154
10	Urban 4-Lane Undivided Unsignalized 3-Leg	3	49	52	153
	Total	214	329	543	17,260

[1] Sidestreet AADT data were acquired from sources without conducting field counts as a part of this project.

Table 2 provides summary statistics for the average yearly accident frequencies and average major and minor road AADTs for the sites used in developing the SPFs. The major road is defined as the roadway with the higher AADT regardless of the roadway classification.

Table 2 Summary Statistics of Data

		Average Major Road AADT			Average Minor Road AADT			Total Accidents/Year			Fatal & Injury Accidents/Year		
ID_Category	**Full Description**	**min**	**max**	**mean**	**min**	**max**	**mean**	**min**	**max**	**mean**	**min**	**max**	**mean**
01_u4xds4	Urban 4-Lane Divided Signalized 4-Leg	5,529	60,183	28,925	917	42,789	13,684	1.00	47.00	15.25	0.20	15.60	4.41
02_u6xds4	Urban 6-Lane Divided Signalized 4-Leg	26,945	60,522	45,729	2,300	46,407	19,005	3.83	50.00	25.74	1.83	15.80	7.18
03_u4xds3	Urban 4-Lane Divided Signalized 3-Leg	4,519	65,549	32,244	341	18,911	6,592	0.33	26.50	7.35	0.17	6.80	2.05
04_u2xu4	Urban 2-Lane Undivided Unsignalized 4-Leg	160	20,262	4,821	68	5,376	986	0.00	9.00	0.61	0.00	4.20	0.23
05_u4xdu4	Urban 4-Lane Divided Unsignalized 4-Leg	4,713	58,791	22,990	50	31,264	3,049	0.00	20.00	3.40	0.00	5.40	1.07
06_u2xu3	Urban 2-Lane Undivided Unsignalized 3-Leg	987	20,021	6,074	7	9,038	1,720	0.00	6.80	0.82	0.00	3.60	0.31
07_u4xdu3	Urban 4-Lane Divided Unsignalized 3-Leg	9,266	59,876	24,653	16	9,936	1,289	0.00	9.00	1.52	0.00	3.00	0.40
08_u4xu4	Urban 4-Lane Undivided Unsignalized 4-Leg	1,451	21,519	7,198	32	2,157	413	0.00	3.33	0.61	0.00	1.33	0.22
09_u2xdu3	Urban 2-Lane Divided Unsignalized 3-Leg	888	23,393	8,363	35	6,015	735	0.00	2.17	0.33	0.00	0.50	0.07
10_u4xu3	Urban 4-Lane Undivided Unsignalized 3-Leg	2,464	40,429	9,598	28	3,295	619	0.00	4.50	0.49	0.00	1.17	0.13

Note: Data plots of total and fatal and injury crash counts per year versus major and minor road AADT are provided for all seven categories in Appendix A.

3.0 STUDY METHODOLOGY

Consistent with state-of-the-art methods, generalized linear models with the specification of a negative binomial error structure were used to develop the intersection SPFs. In turn, the specification of a negative binomial error structure allows for the estimation of an overdispersion parameter that is used in the empirical Bayes procedure for estimating the expected safety performance of an intersection for various safety management purposes (e.g., those envisaged in *SafetyAnalyst*[1]).

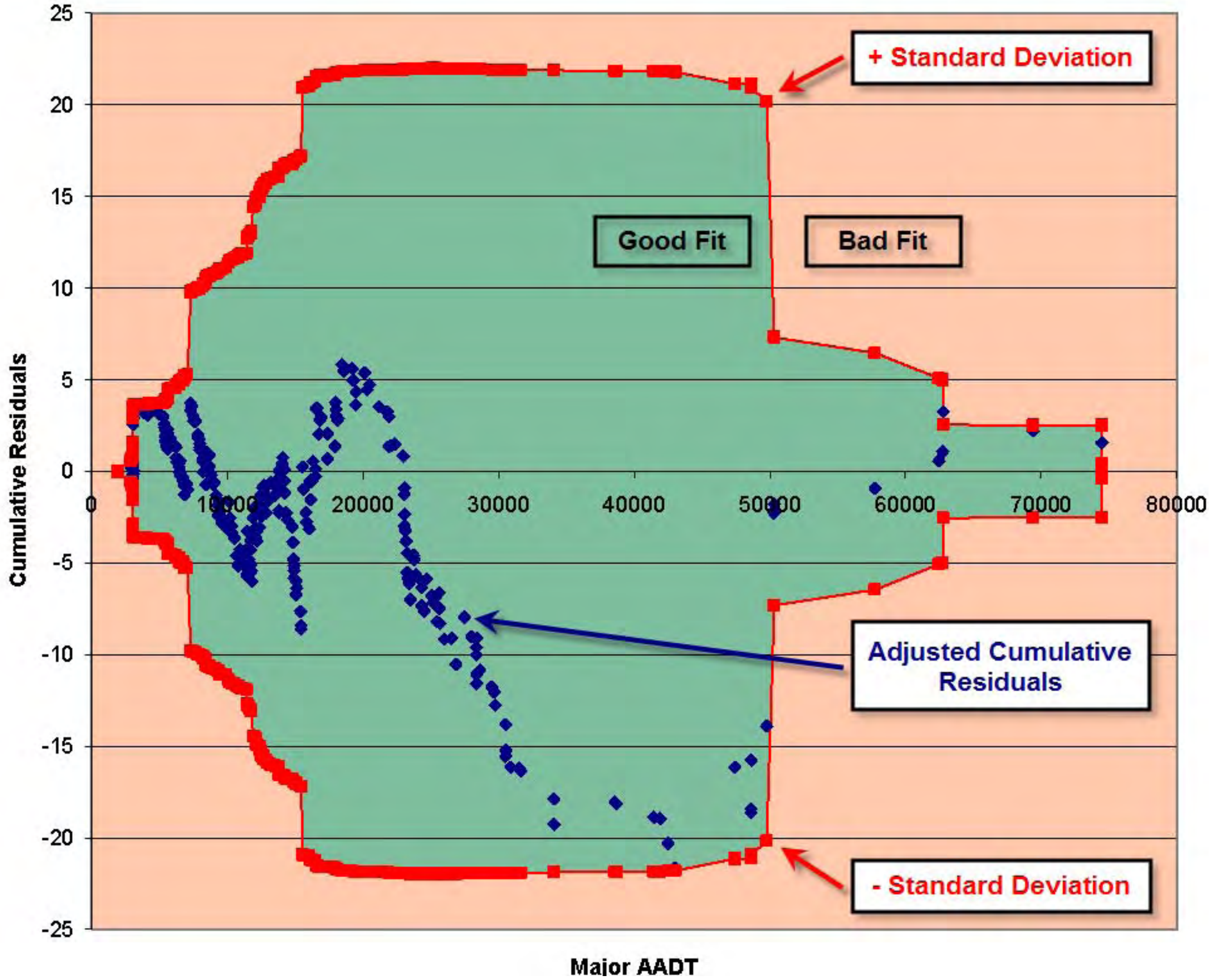
SPFs were developed separately for total and injury (fatal+injury) accidents. In developing the SPFs, alternative model forms were investigated using the integrate-differentiate (ID) method documented by Hauer[2]. Briefly, this method involves plotting the cumulative products of the accident count and the value of the independent variable of interest against the variable of interest. While it is typically difficult to observe patterns on simple plots of accident frequency against an independent variable (such as traffic volume), this cumulative plot makes such patterns much easier to spot. The relationship between accident frequency and the variable of interest is then the derivative of this observed relationship.

Alternative models were compared using other standard measures of goodness-of-fit such as the mean residuals (observed-predicted) and the value of the overdispersion parameter which is estimated as part of the modeling process and is in itself a reliable goodness-of-fit measure. It is important to not only evaluate a model based on overall measures but also to evaluate how it performs over the range of covariates. This evaluation makes use of cumulative residual (CURE) plots. In the Cumulative Residuals (CURE) method, documented by Hauer & Bamfo[2], the cumulative residuals (the difference between the observed and predicted values for each site) are plotted in increasing order for each covariate separately. Also plotted are graphs of the 95% confidence limits. If there is no bias in the model, the plot of cumulative residuals should stay inside of these limits. The graph shows how well the model fits the data with respect to each individual covariate. **Figure 1** illustrates a CURE plot for the covariate of Major road AADT. The indication is that the fit is very good for this covariate in that the cumulative residuals oscillate around the value of zero and lie between the two standard deviation boundaries.

[1] http://www.safetyanalyst.org/

[2] Hauer, E. and J. Bamfo, “Two Tools for Finding What Function Links the Dependent Variable to the Explanatory Variables”. Available at www.roadsafetyresearch.com.

Figure 1 Example of CURE Plot



4.0 SPFs CALIBRATED

Models were successfully developed for each of the ten intersection categories. In consideration of poorer model performance, models for Category 7 were derived by combining Categories 6 and 7 (Urban 2-Lane Undivided Unsignalized 3-Leg and Urban 4-Lane Divided Unsignalized 3-Leg) and included a factor variable to differentiate Category 7 from Category 6. The reported models should be applied to Category 7 intersections directly as shown. The recommended models for Category 6 were derived using solely Category 6 intersection data. Exploration of unconventional model forms was not particularly successful although this was not surprising given the relatively small sample sizes available. Geometric data, other than number of lanes and divided/undivided median used for creating intersection categories, was not available for modeling.

Table 3 provides the SPFs developed for total accidents. The magnitude of the estimated parameters is in line with that for models calibrated for other jurisdictions. The standard errors of the estimated parameters indicate that they are highly significant. The properties of the standard errors are such that an estimated parameter is within the range of the estimated value plus or minus 1.64 standard errors with 90 percent confidence. If this range does not include the value of 0, then the parameter is significant at the 90 percent level. As an example, for the Category 1 model in Table 3, the parameter $\beta 1$ is estimated as 1.5811 with a standard error of 0.3894. Thus the 90% confidence interval of the estimated parameter is 0.9425 to 2.2197. Because this range does not include the value 0, it can be stated that the estimated parameter is statistically significant at the 90% level. The overdispersion parameters also indicate that the models provide a reasonable fit to the data. Note that the properties of the overdispersion parameter are such that smaller values indicate a stronger fit to the data. Although there are no rules as to how small the overdispersion parameter should be to be considered acceptable, experience indicated that values of approximately 1.0 or less are quite satisfactory.

Table 3 Summary of Total Accident Models

Model Form[1]
Accidents/year = exp(ln α) • (MajAADT)$^{\beta 1}$ • (MinAADT)$^{\beta 2}$ • exp(majvar • β3)

Category	Full Description	ln(α) (s.e.)	β1 (s.e.)	β2 (s.e.)	β3 (s.e.)	Over-dispersion Parameter
1	Urban 4-Lane Divided Signalized 4-Leg	-17.4479 (3.5681)	1.5811 (0.3894)	0.4985 (0.0517)	-0.2585 (0.1521)	0.1343
2	Urban 6-Lane Divided Signalized 4-Leg	-10.2337 (1.9973)	0.7006 (0.1738)	0.6122 (0.0532)		0.0637
3	Urban 4-Lane Divided Signalized 3-Leg	-10.5520 (2.5937)	0.7596 (0.2248)	0.5425 (0.1077)		0.4100
4	Urban 2-Lane Undivided Unsignalized 4-Leg	-13.4810 (1.8944)	0.9810 (0.2161)	0.6658 (0.1399)		0.4012
5	Urban 4-Lane Divided Unsignalized 4-Leg	-9.3250 (1.4602)	0.7329 (0.1529)	0.4207 (0.0656)		0.2949
6	Urban 2-Lane Undivided Unsignalized 3-Leg	-10.5144 (1.7524)	0.7080 (0.2057)	0.5597 (0.1215)		0.3771
7	Urban 4-Lane Divided Unsignalized 3-Leg	-10.6568 (1.7794)	0.8999 (0.1808)	0.3019 (0.0857)		0.7143
8	Urban 4-Lane Undivided Unsignalized 4-Leg	-18.4705 (1.6816)	1.5927 (0.1579)	0.6091 (0.1221)		0.1073
9	Urban 2-Lane Divided Unsignalized 3-Leg	-12.8076 (2.3983)	0.9530 (0.2759)	0.4772 (0.1140)		0.5157
10	Urban 4-Lane Undivided Unsignalized 3-Leg	-10.9476 (2.0796)	0.7290 (0.2051)	0.5746 (0.1640)		0.6135

[1] MajAADT and MinAADT ranges are reported in **Table 2** on page 5.

Where,

MajAADT = the average major road AADT

MinAADT = the average minor road AADT

Majvar = the average major road AADT/10,000

Table 4 provides the SPFs developed for fatal+injury accidents. As was the case for the total accident SPFs, the magnitude of the estimated parameters are in line with models calibrated for other jurisdictions, and the standard errors of the estimated parameters indicate that they are highly significant. For categories 8 and 9 satisfactory models were not found using fatal+injury accidents. The models for these categories were obtained by adjusting the ln(α) parameters of the models in **Table 3** by the proportion of total crashes that are fatal+injury severity. The overdispersion parameters also indicate that the models provide a reasonable fit to the data.

Table 4 Summary of Fatal and Injury Accidents Models

Model Form[1] Accidents/year = $\exp(\ln \alpha) \cdot (MajAADT)^{\beta 1} \cdot (MinAADT)^{\beta 2} \cdot \exp(majvar \cdot \beta 3)$						
Category	**Full Description**	**ln(α) (s.e.)**	**β1 (s.e.)**	**β2 (s.e.)**	**β3 (s.e.)**	**Over-dispersion Parameter**
1	Urban 4-Lane Divided Signalized 4-Leg	-20.6848 (5.0031)	1.8508 (0.5450)	0.4547 (0.0629)	-0.3743 (0.1995)	0.1546
2	Urban 6-Lane Divided Signalized 4-Leg	-8.3311 (2.1282)	0.4761 (0.1872)	0.5335 (0.0588)		0.0566
3	Urban 4-Lane Divided Signalized 3-Leg	-11.0639 (3.1904)	0.7215 (0.2765)	0.5027 (0.1186)		0.3747
4	Urban 2-Lane Undivided Unsignalized 4-Leg	-14.0091 (2.8381)	0.7689 (0.3362)	0.8512 (0.2327)		0.9044
5	Urban 4-Lane Divided Unsignalized 4-Leg	-8.0295 (1.8901)	0.4993 (0.1981)	0.4137 (0.0859)		0.3868
6	Urban 2-Lane Undivided Unsignalized 3-Leg	-10.4668 (2.5076)	0.6024 (0.3014)	0.5449 (0.1873)		0.6116
7	Urban 4-Lane Divided Unsignalized 3-Leg	-11.6429 (2.4706)	0.8642 (0.2495)	0.3022 (0.1240)		1.0810
8	Urban 4-Lane Undivided Unsignalized 4-Leg	-19.5005 (1.6816)	1.5927 (0.1579)	0.6091 (0.1221)		0.1073
9	Urban 2-Lane Divided Unsignalized 3-Leg	-14.4121 (2.3983)	0.9530 (0.2759)	0.4772 (0.1140)		0.5157
10	Urban 4-Lane Undivided Unsignalized 3-Leg	-12.6932 (2.9959)	0.7577 (0.2763)	0.5914 (0.2350)		0.3730

[1] MajAADT and MinAADT ranges are reported in **Table 2** on page 5.

Where,

MajAADT = the average major road AADT

MinAADT = the average minor road AADT

Majvar = the average major road AADT/10,000

Cumulative Residual Plots for the SPFs for both major and minor road AADT are provided for all ten categories in **Appendix B**. The CURE plots further indicate that the models are fitting the data well. The plots of cumulative residuals are largely within the two standard error boundaries. When the cumulative residuals do stray outside these limits, the magnitude of the cumulative residuals compared to the total number of crashes is relatively small.

5.0 MODEL PLOTS

Since the models are based on two input variables (major and minor road AADT), illustrations of the model results would need to be three dimensional. To show typical results, the models were all plotted for the major approach AADT data range using a mid-range minor approach AADT of 15,000 for signalized intersections and 1,000 for unsignalized intersections. Four separate plots are shown below for signalized and unsignalized intersections and for total and fatal plus injury collisions. Also shown on these plots are the comparable Highway Safety Manual models for urban and suburban arterials. The HSM model predictions are from a summation of predictions from models for multi-vehicle and single vehicle collisions.

SIGNALIZED INTERSECTIONS

Figure 2 Signalized TOTAL (Minor AADT = 15,000)

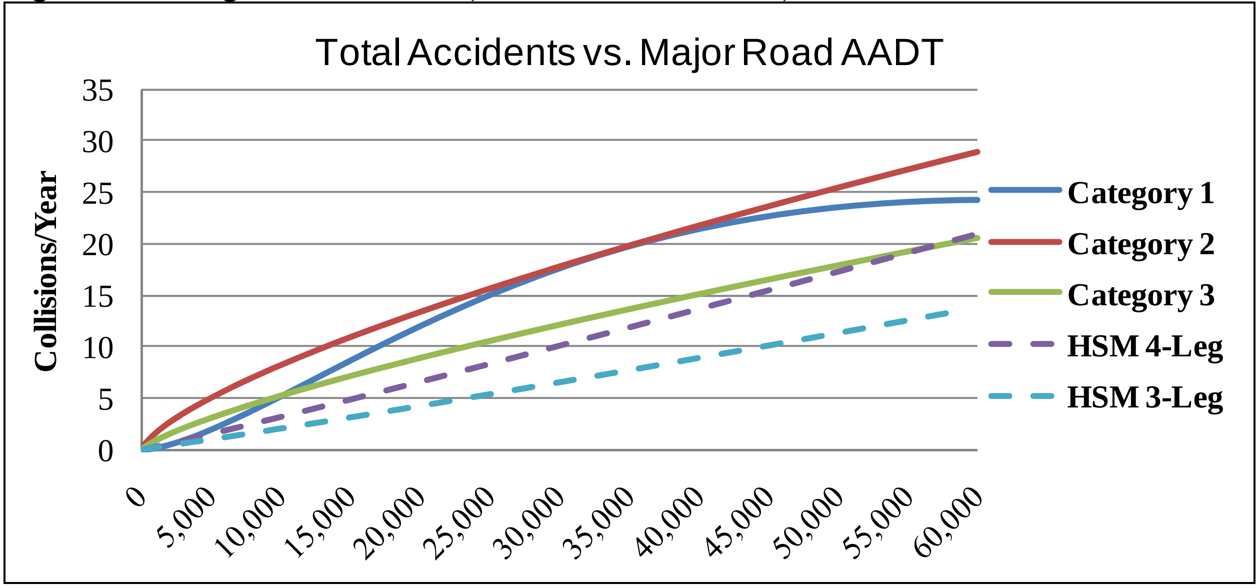
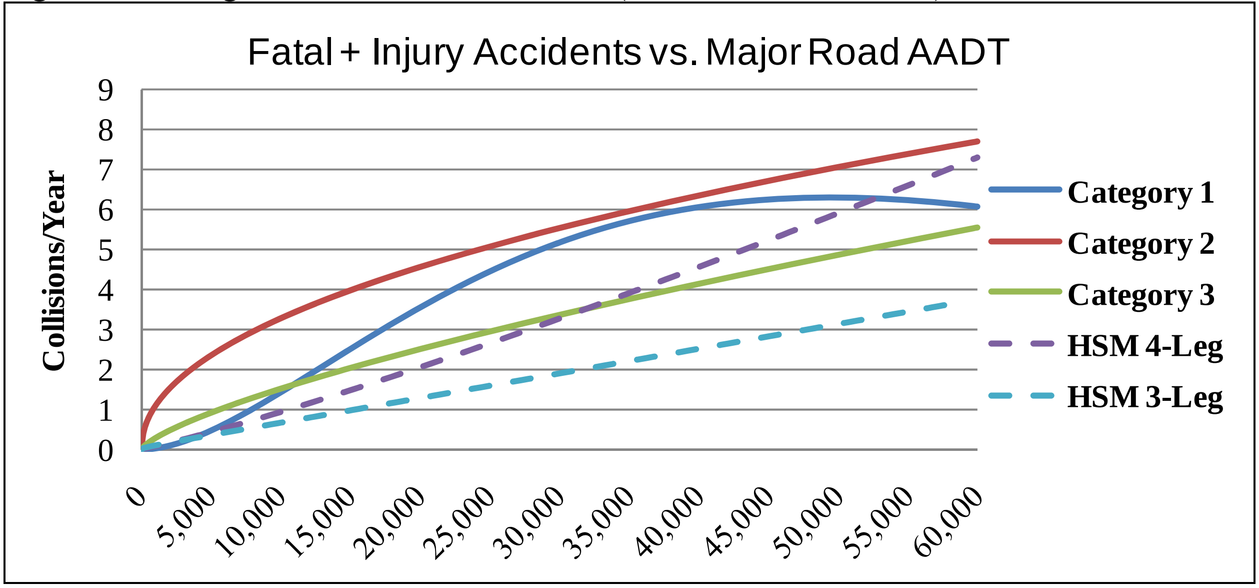


Figure 3 Signalized FATAL + INJURY (Minor AADT = 15,000)



UNSIGNALIZED INTERSECTIONS

Figure 4 Unsignalized TOTAL (Minor AADT = 1,000)

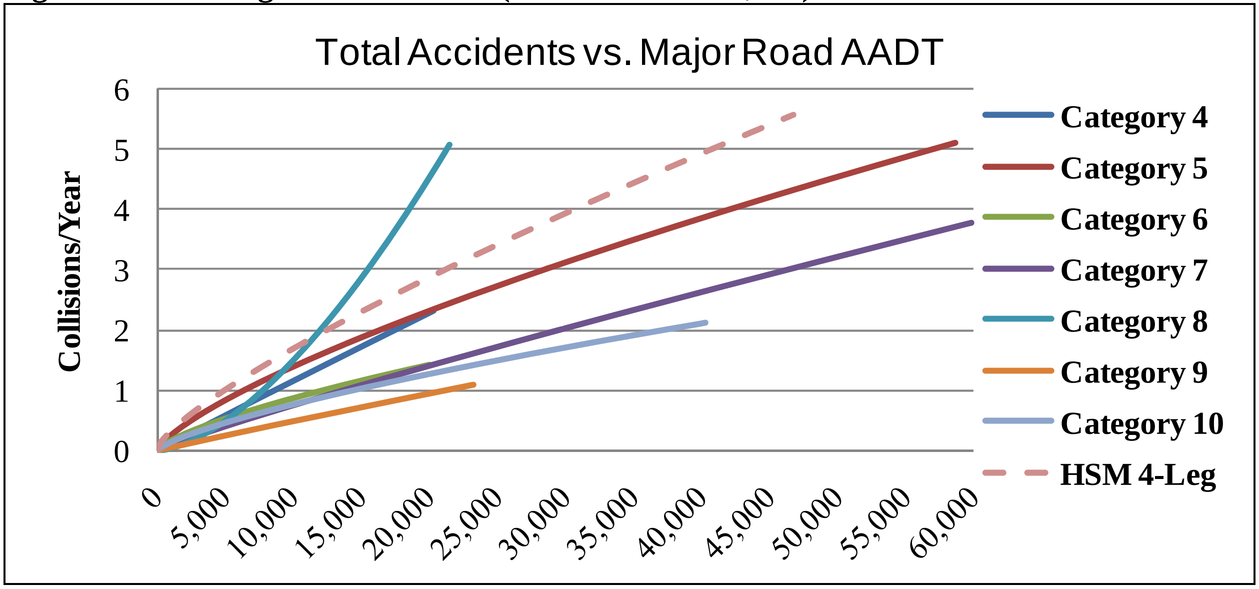
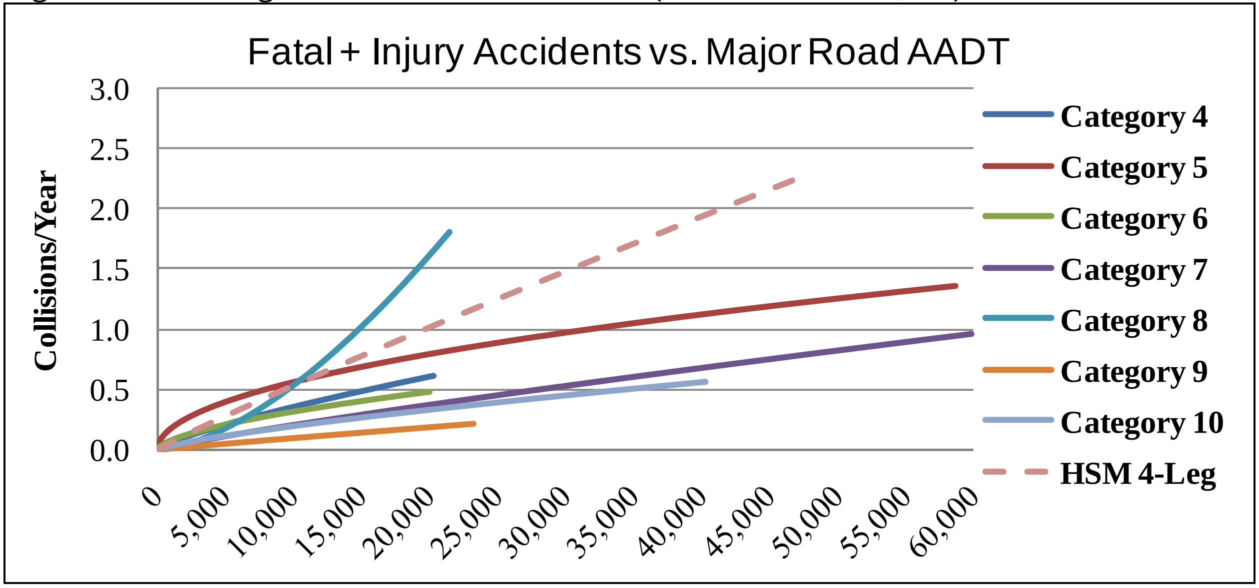


Figure 5 Unsignalized FATAL + INJURY (Minor AADT = 1,000)



The following cautious observations can be made from these plots, all else assumed to be equal:

SIGNALIZED INTERSECTIONS (Figures 2 and 3)

- Roads with 6-lanes on the major approaches have more collisions than roads with 4-lanes on the major
- The HSM models predict fewer collisions for both 4 and 3 legs than the Colorado models for most of the range of major road AADT. (The HSM models pertain to intersections with various numbers of approach lanes and do not include pedestrian and bicycle crashes.)

UNSIGNALIZED INTERSECTIONS (Figures 4 and 5)

- For both the 2- and 4-lane major road approach categories for TOTAL and Fatal+Injury collisions, Colorado 3-legged intersections have substantially fewer collisions than 4-legged intersections. The same can generally be said for the HSM models.
- For both TOTAL and Fatal+Injury collisions at unsignalized intersections, the HSM model for 4-leg intersections generally predicts between the Colorado models for 2-lane divided and 4-lane undivided; the HSM model for 3-leg intersections generally predicts more collisions than the Colorado 3-leg models.

6.0 RECALIBRATION PROCEDURE

The SPFs developed apply to similar intersections under CDOT jurisdiction during the time period for which the data were collected. It may be desirable at a future time period to recalibrate the models for data from future years. Expected accident frequencies may change over time due to issues such as changes to reporting practices, demographics, state-wide safety programs etc. Additionally, for intersection categories for which SPFs were not developed, it may be desirable to recalibrate SPFs developed from other jurisdictions for application in Colorado. Both instances require a recalibration of the original SPFs.

The desirable recalibration sample size would be such that there are a minimum of 30 to 50 sites of the same site type and at least 100 observed accidents per year. Additionally, it might be desirable to assemble separate sets of sites and develop separate calibration factors for level, rolling and mountainous terrain and/or different regions if so desired.

For the sample, data is collected to apply the SPFs to predict the number of accidents at each site. The ratio of the sums of observations to sum of predictions is used as an estimate of the calibration factor. This calibration factor is then added as a multiplier to the original SPF.

It is also logical to recalibrate the overdispersion parameter as this not only indicates how well the recalibrated SPF is fitting the data but can also be used in the empirical Bayes methodology. Procedures with varying complexities for recalibrating the overdispersion parameter are provided below.

6.1 Estimation of overdispersion parameter (*k*) by maximum likelihood

The maximum likelihood method estimates the most likely value of the dispersion parameter and is the preferred approach as it is more accurate. The log-likelihood is calculated for a range of possible values of *k*, and the value of *k* with the largest log-likelihood is selected. If there is no such peak in the initial range selected, then a broader range of potential values of *k* is used. It is recommended to initially use values of *k* in increments of 0.5 to get a rough estimate and then to use increments of 0.05 to arrive at the final estimate of *k*.

For each of *j* = 1 to N sites, the following equations are applied:

a = (1/*k*)*LOG((1/*k*)/predicted);

b = ((1/k) +observed)*LOG((1/*k*)/predicted+1);

$$c = \sum_{i=1}^{observed} LOG((1/k)+i-1)$$

where, the log-likelihood for k is then calculated as:

k	=	the dispersion parameter
predicted	=	the number of crashes predicted at site *j* by the recalibrated accident prediction model
observed	=	the crash frequency observed at site *j*

The log-likelihood for k is then calculated as:

$$Log - Likelihood = \sum_{j=1}^{N} a - \sum_{j=1}^{N} b + \sum_{j=1}^{N} c$$

Illustration - As an example, consider a fictitious dataset of sites including the following site j:

<u>Site *j*</u>
Observed crash frequency = 4
Predicted crash frequency = 4.5

Now consider that the analyst has selected a range of *k* from 0.25 to 1.25 in increments of 0.05. To illustrate the use of the above equations we will use the value of *k* = 0.40

a = (1/0.40)*LOG((1/0.40)/4.5) = 2.2447
b = ((1/0.40)+4)*LOG((1/0.40)/4.5+1) = 1.2473
c = LOG(1/0.40+1-1)+ LOG(1/0.40+2-1)+ LOG(1/0.40+3-1)+ LOG(1/0.40+4-1) = 2.3356

Similar calculations are then performed for each site and the log-likelihood calculated. For *k* = 0.40, the table below shows that the log-likelihood is estimated as 2705.

The log-likelihood is calculated for all possible values of *k* selected. As can be seen in **Table 5**, there is a peak value of the log-likelihood when *k* = 0.75 and the value of log-likelihood is 2718. Thus the estimated value of *k* is 0.75.

Table 5 Peak Value of the Log-Likelihood

k	Log-Likelihood
0.25	2700
0.30	2702
0.35	2703
0.40	2705
0.45	2707
0.50	2708
0.55	2711
0.60	2712
0.65	2714
0.70	2716
0.75	2718
0.80	2717
0.85	2715
0.90	2714
0.95	2713
1.00	2712
1.05	2710
1.10	2708
1.15	2707
1.20	2705
1.25	2704

6.2 Estimation of overdispersion parameter (*k*) by linear regression

Step 1: For each site, use the recalibrated accident prediction model to estimate the expected number of accidents (*P*). Also compute P^2.

Step 2: For each site, determine the value of the squared residual (*SR*):

$$SR = (P - Accident\ count)^2$$

Step 3: Subtract the value of *P* from the squared residual (SR). This gives an estimate of $P^2 * k$:

$$[\text{Estimate of } P^2 * k] = SR - P$$

Step 4: Fit a linear model through the origin with $P^2 * k$ as the dependent variable and P^2 as the independent variable. An ordinary least squared regression procedure such as can be executed in MS EXCEL should suffice.

Step 5: The calibrated slope of the regression line is an estimate of *k*.

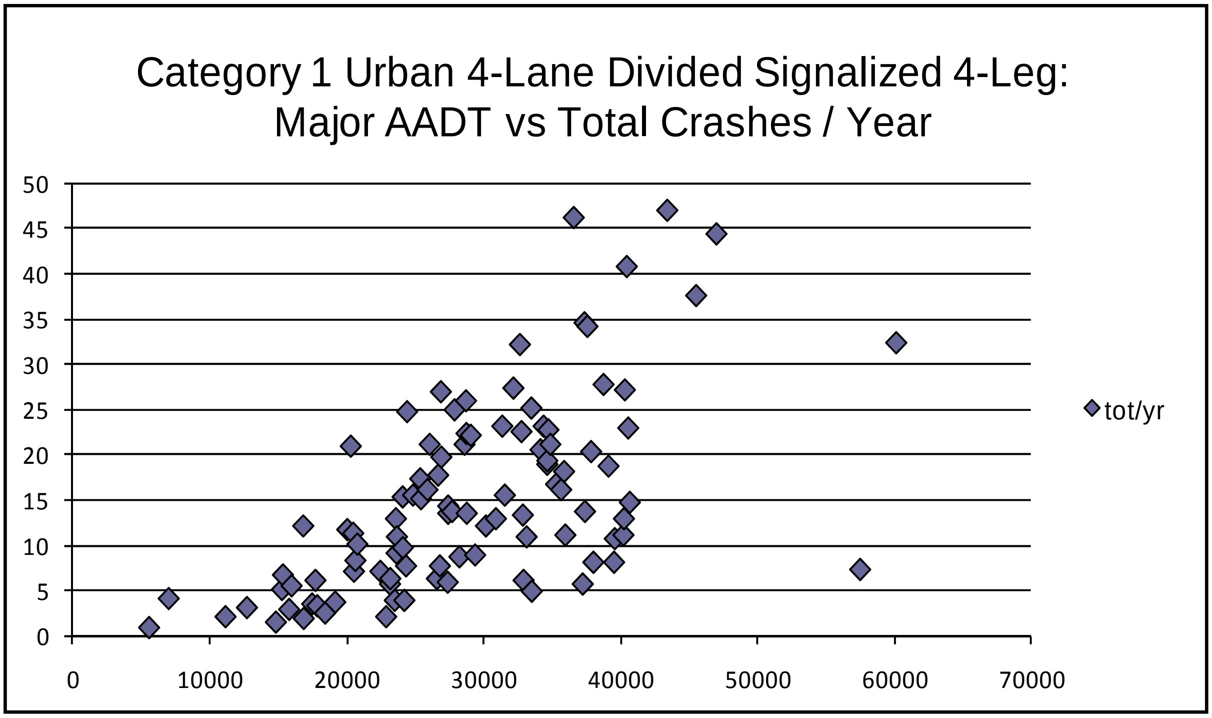
7.0 CONCLUSIONS AND RECOMMENDATIONS

The development of SPFs for ten intersection categories was successful. Separate models were developed for total and for injury (fatal+injury) accidents.

It is recommended that data for additional sites be collected as they may become available. Additionally, as more years of crash and traffic data become available, these data too can be added to the dataset in order to continually add up-to-date information. The models can be recalibrated to apply to these additional years of data. When several additional years of data are available, it may be desirable to calibrate a new set of original SPFs.

APPENDIX A

DATA PLOTS


Category 1 Urban 4-Lane Divided Signalized 4-Leg:
Major AADT vs Total Crashes / Year
50
45
40
35
30
25
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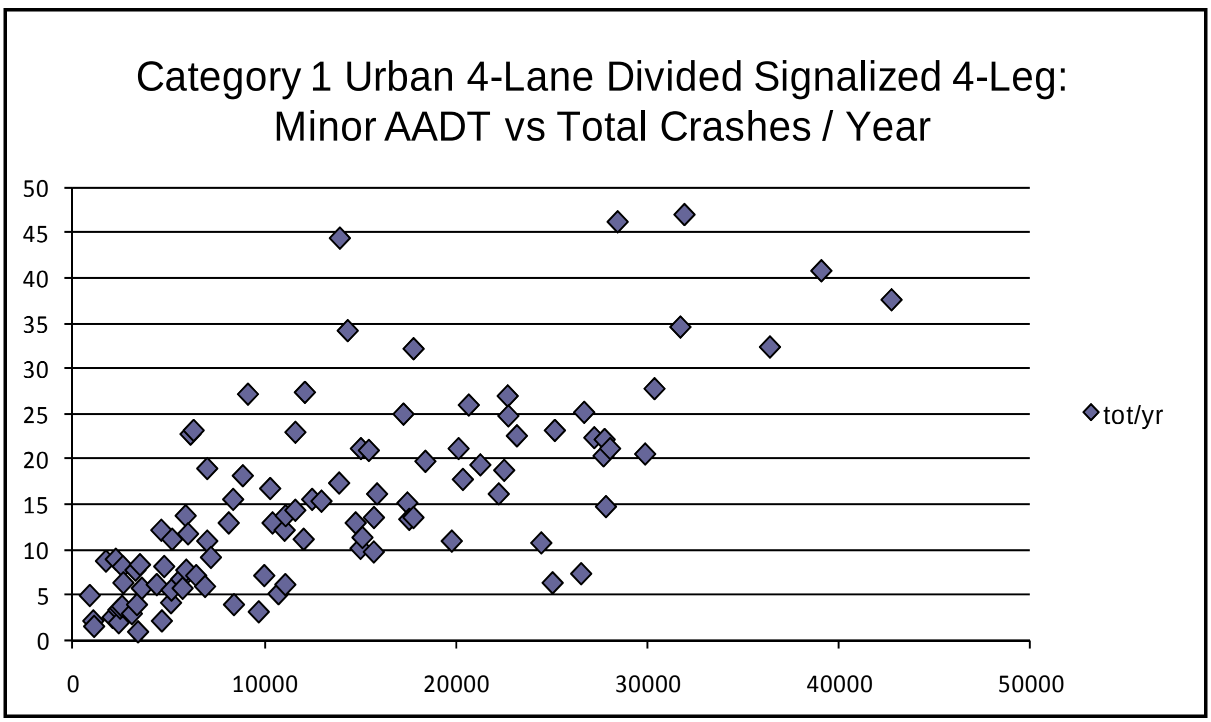
15
10
5
0
0
10000
20000
30000
40000
50000
60000
70000
tot/yr


Category 1 Urban 4-Lane Divided Signalized 4-Leg:
Minor AADT vs Total Crashes / Year
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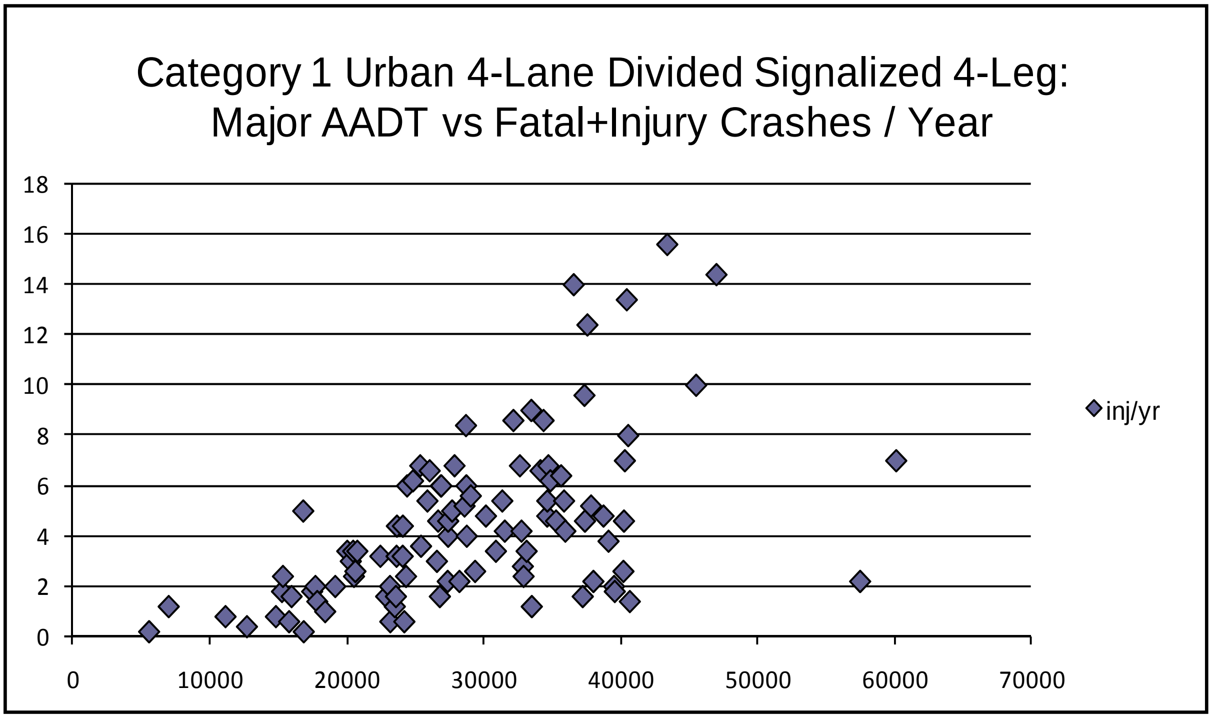
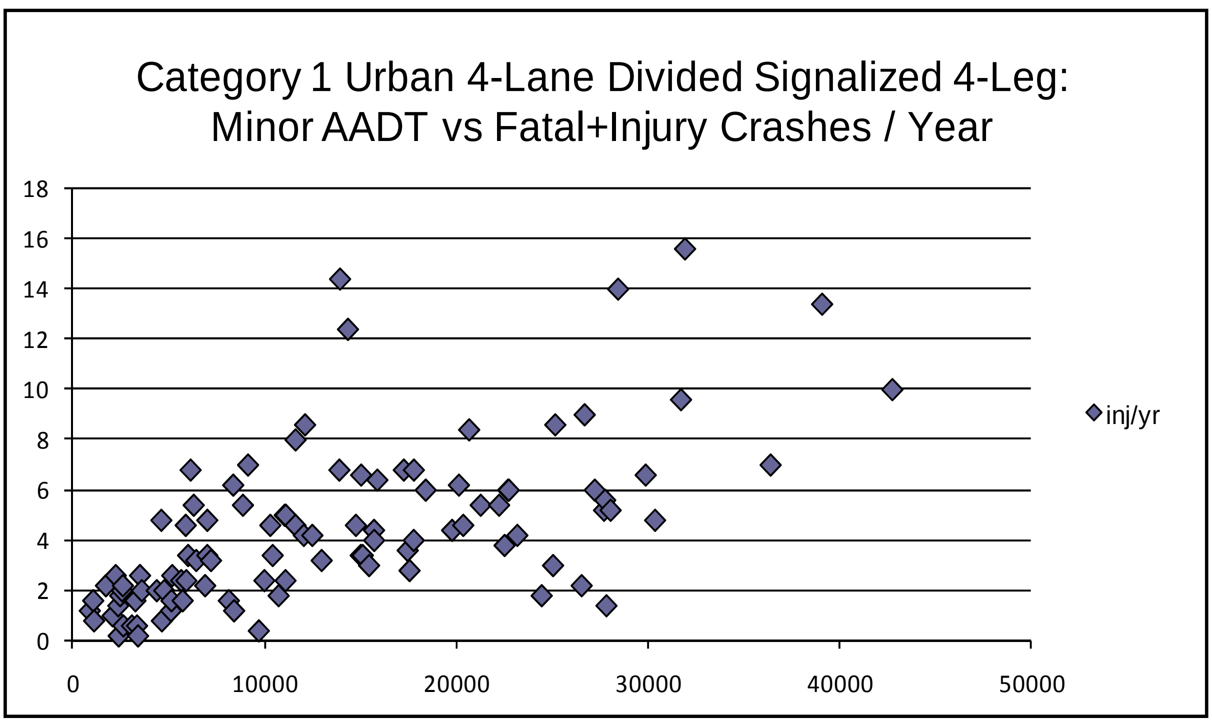
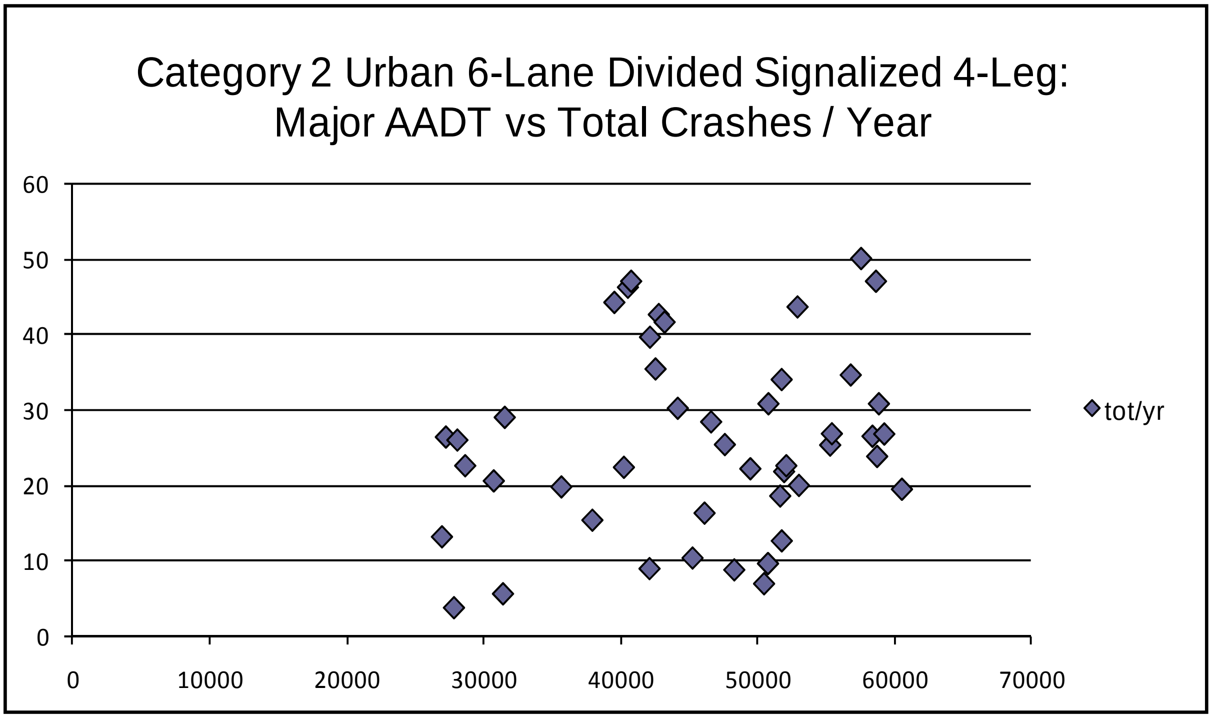
35
30
25
20
15
10
5
0
0
10000
20000
30000
40000
50000
tot/yr



Category 1 Urban 4-Lane Divided Signalized 4-Leg:
Major AADT vs Fatal+Injury Crashes / Year
18
16
14
12
10
8
6
4
2
0
0
10000
20000
30000
40000
50000
60000
70000
inj/yr



Category 1 Urban 4-Lane Divided Signalized 4-Leg:
Minor AADT vs Fatal+Injury Crashes / Year
18
16
14
12
10
8
6
4
2
0
0
10000
20000
30000
40000
50000
inj/yr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Major AADT vs Total Crashes / Year
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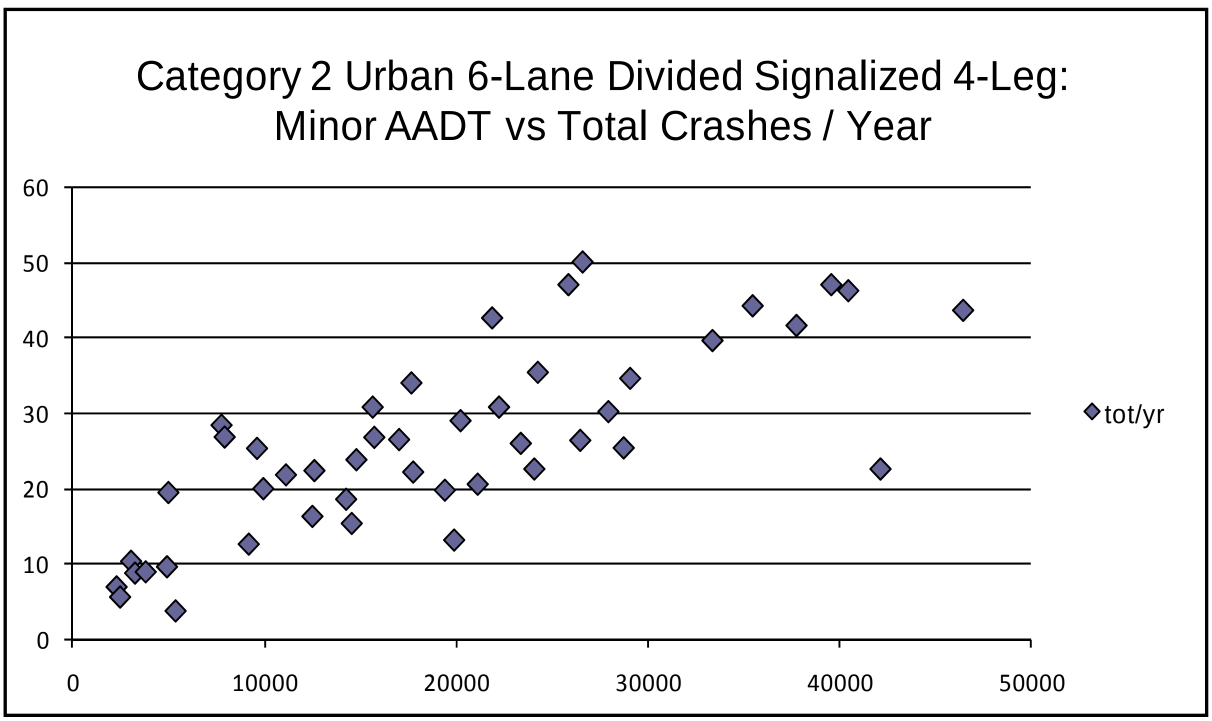
20
30
40
50
60
0
10000
20000
30000
40000
50000
60000
70000
tot/yr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Minor AADT vs Total Crashes / Year
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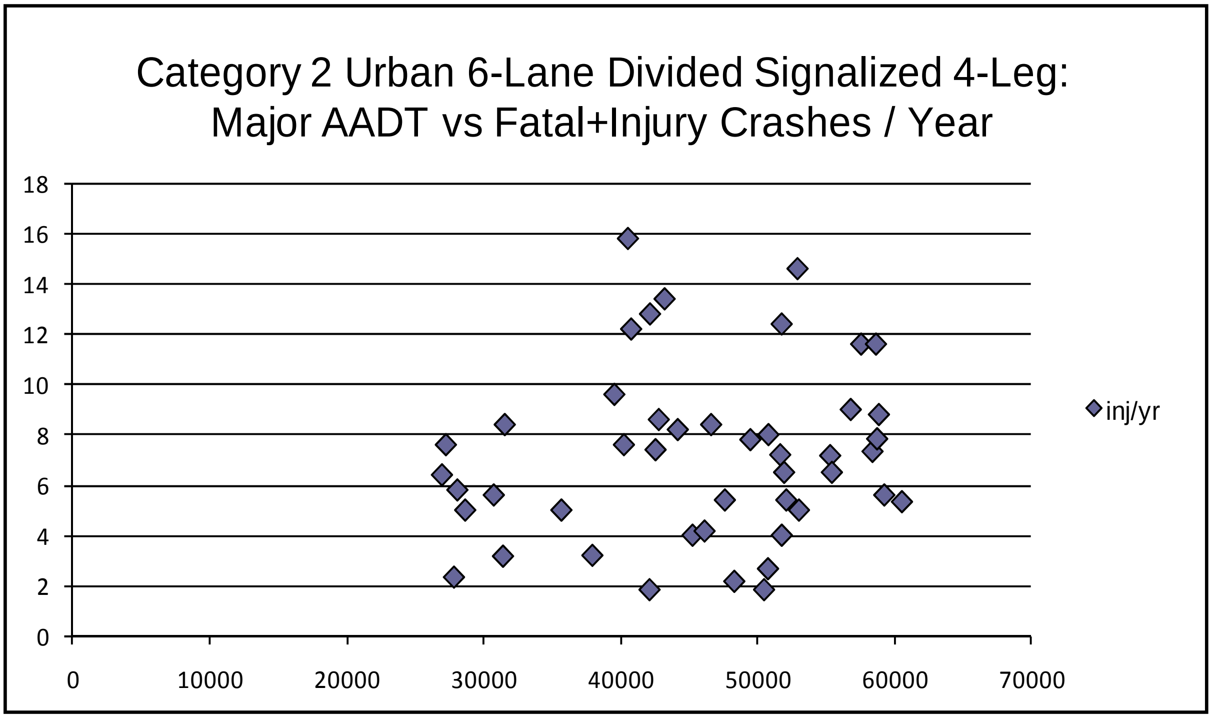
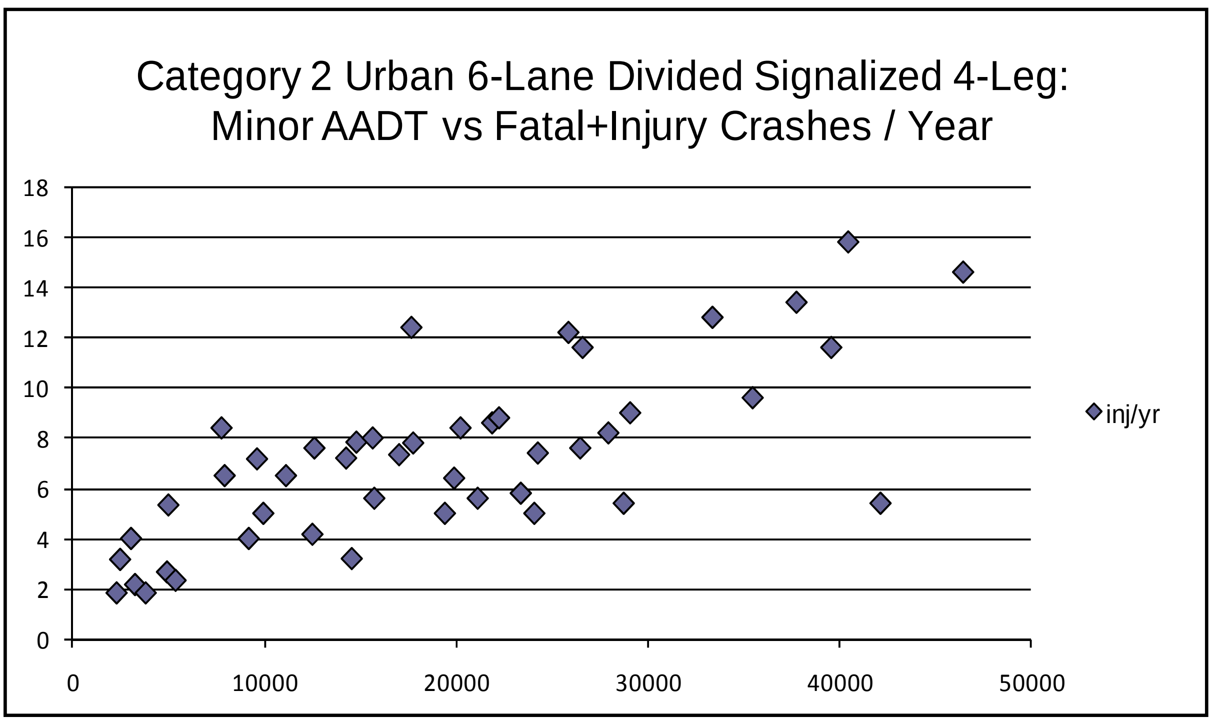
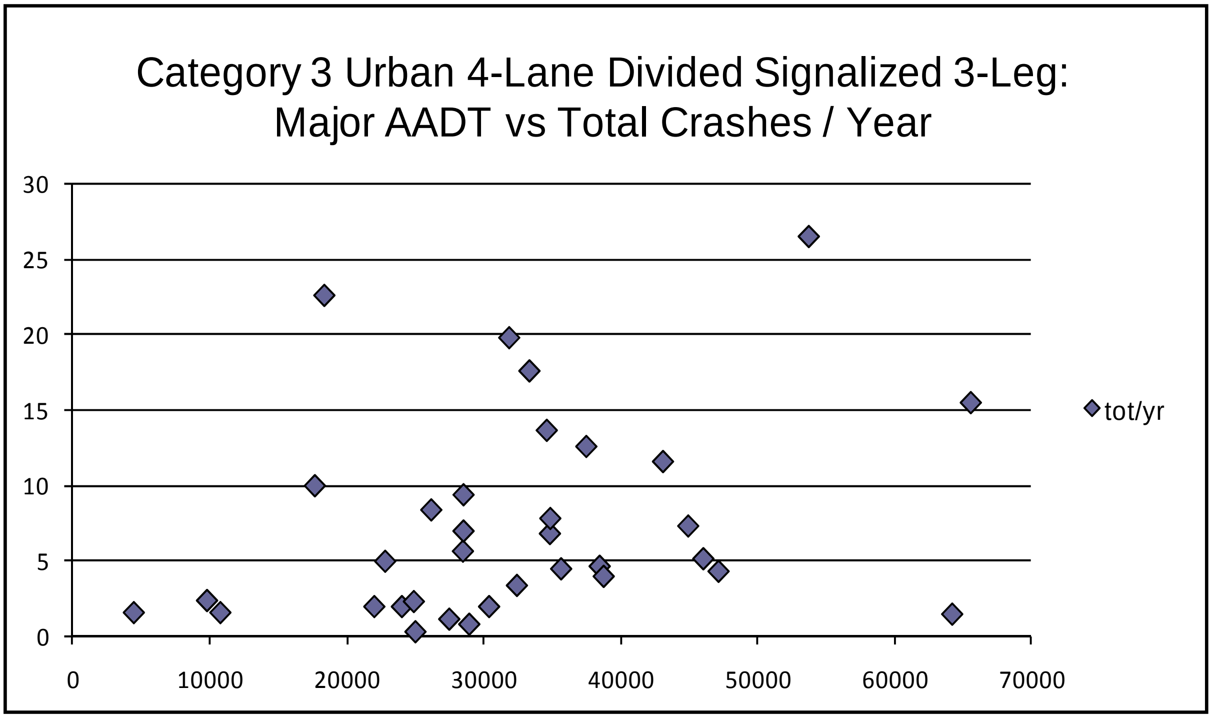
20
30
40
50
60
0
10000
20000
30000
40000
50000
tot/yr



Category 2 Urban 6-Lane Divided Signalized 4-Leg:
Major AADT vs Fatal+Injury Crashes / Year
18
16
14
12
10
8
6
4
2
0
0
10000
20000
30000
40000
50000
60000
70000
inj/yr



Category 2 Urban 6-Lane Divided Signalized 4-Leg:
Minor AADT vs Fatal+Injury Crashes / Year
18
16
14
12
10
8
6
4
2
0
0
10000
20000
30000
40000
50000
inj/yr


Category 3 Urban 4-Lane Divided Signalized 3-Leg:
Major AADT vs Total Crashes / Year
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15
10
5
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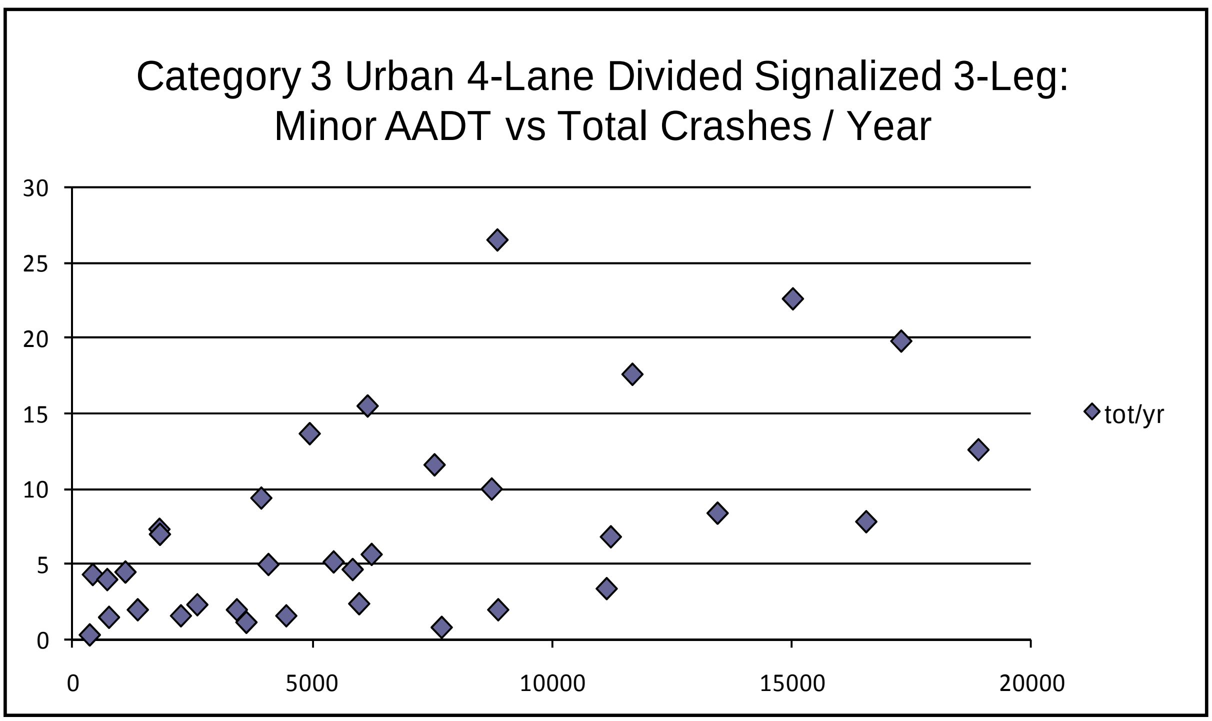
0
10000
20000
30000
40000
50000
60000
70000
tot/yr


Category 3 Urban 4-Lane Divided Signalized 3-Leg:
Minor AADT vs Total Crashes / Year
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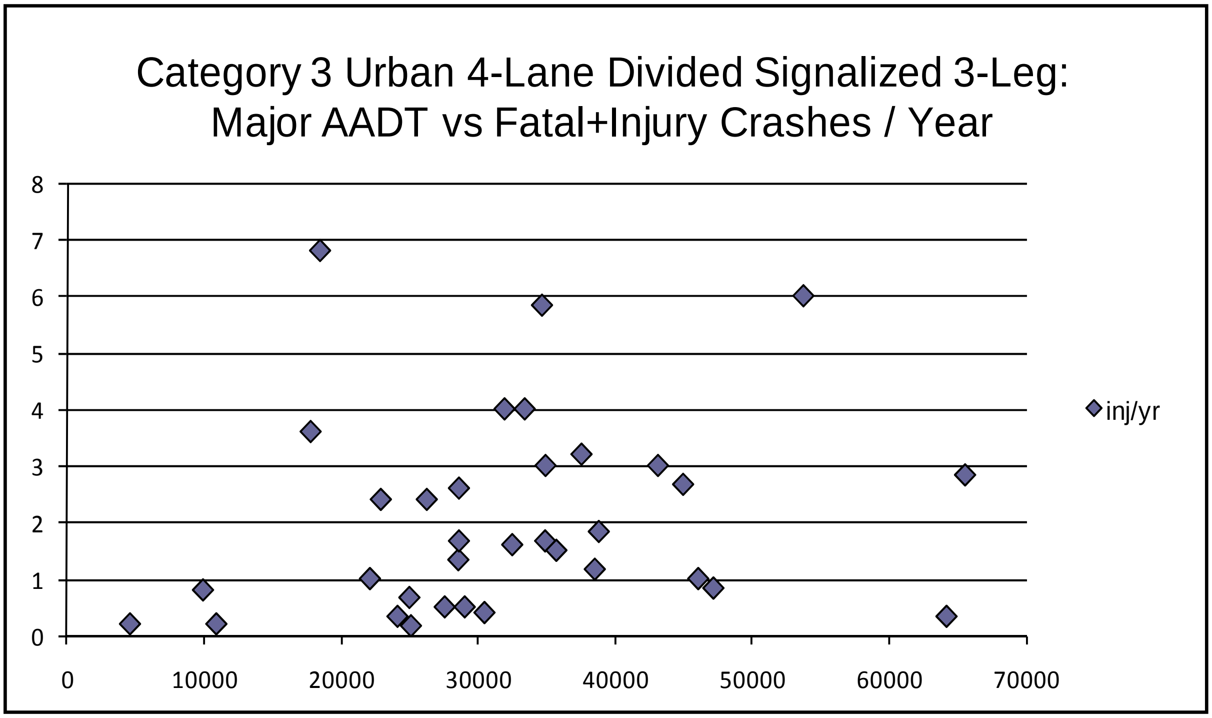
20
15
10
5
0
0
5000
10000
15000
20000
tot/yr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Major AADT vs Fatal+Injury Crashes / Year
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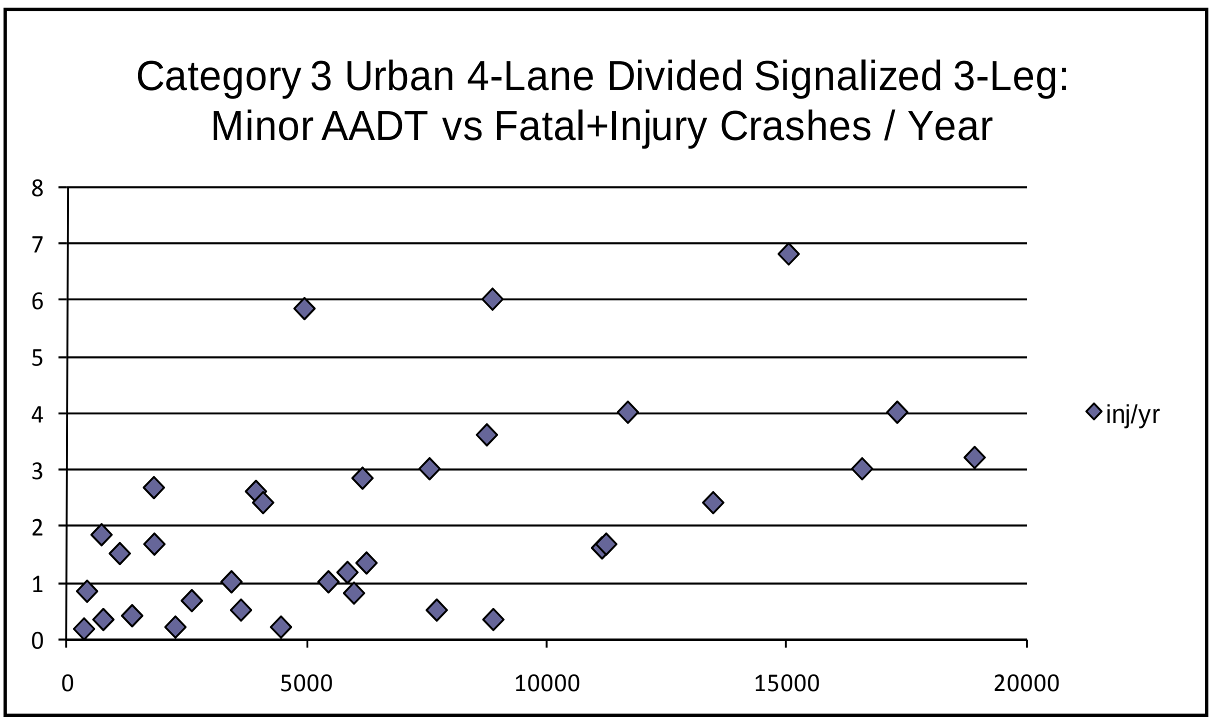
1
2
3
4
5
6
7
8
0
10000
20000
30000
40000
50000
60000
70000
inj/yr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Minor AADT vs Fatal+Injury Crashes / Year
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1
2
3
4
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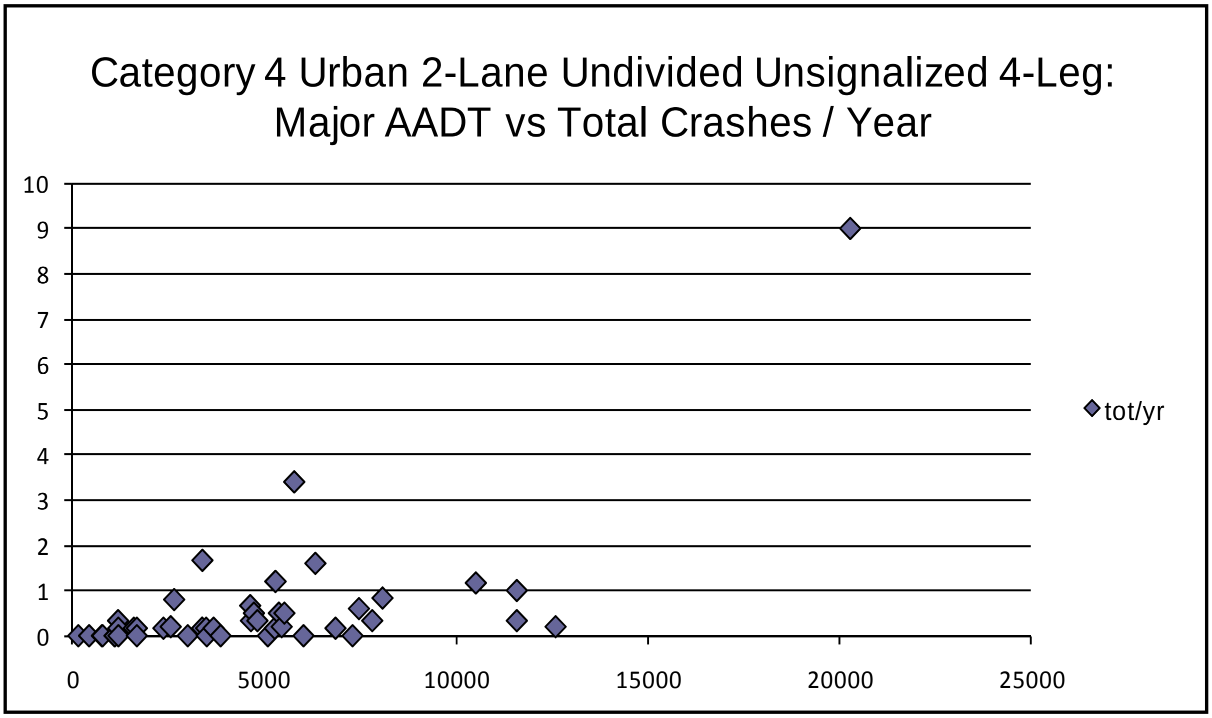
6
7
8
0
5000
10000
15000
20000
inj/yr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Major AADT vs Total Crashes / Year
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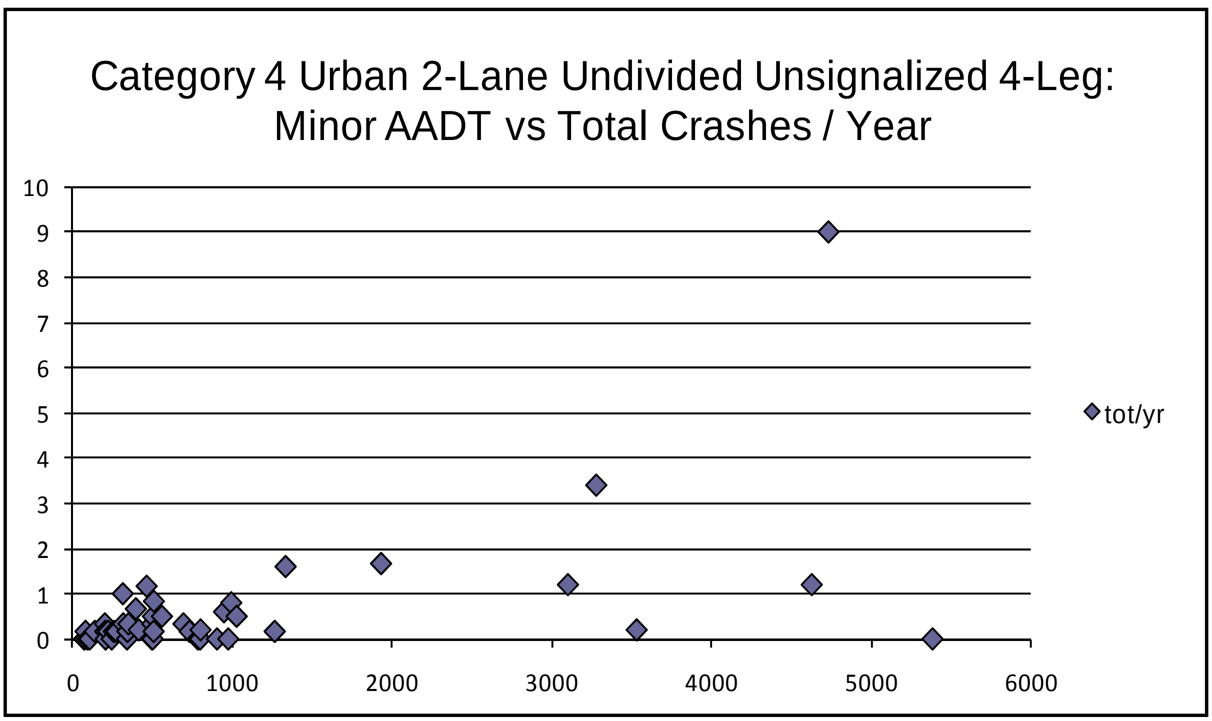
6
5
4
3
2
1
0
0
5000
10000
15000
20000
25000
tot/yr


Category 4 Urban 2-Lane Undivided Unsignalized 4-Leg:
Minor AADT vs Total Crashes / Year
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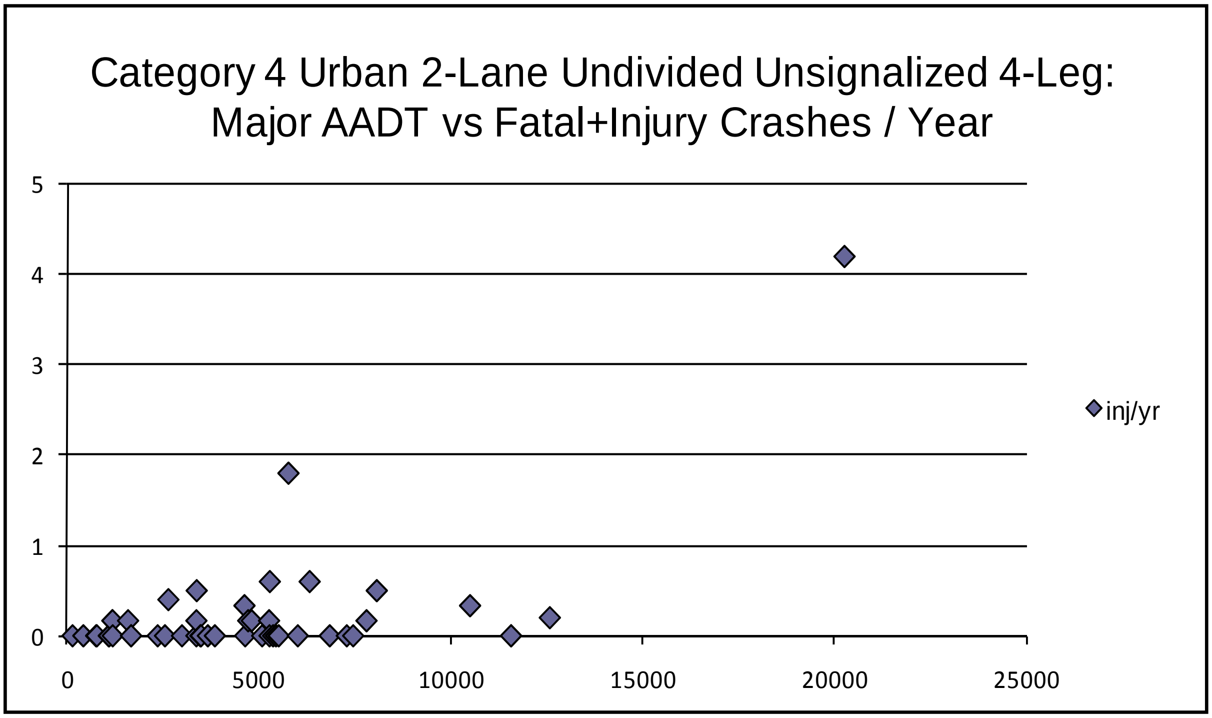
7
6
5
4
3
2
1
0
0
1000
2000
3000
4000
5000
6000
tot/yr


Category 4 Urban 2-Lane Undivided Unsignalized 4-Leg:
Major AADT vs Fatal+Injury Crashes / Year
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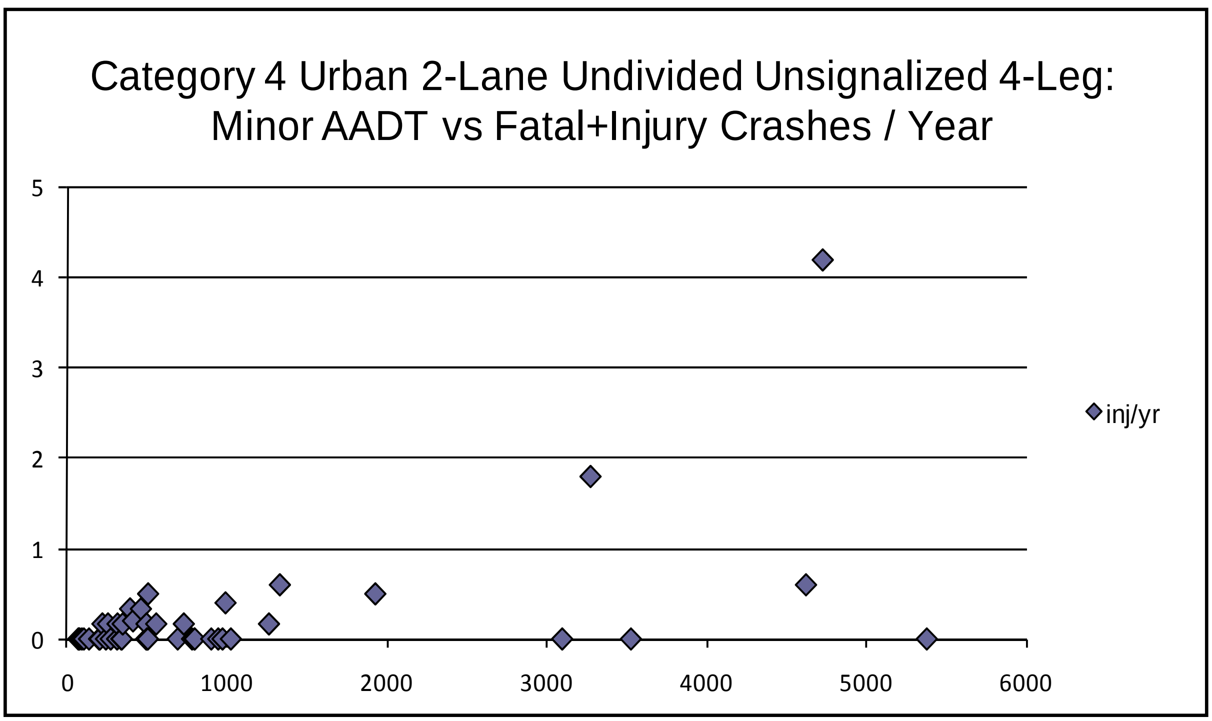
4
3
2
1
0
0
5000
10000
15000
20000
25000
inj/yr


Category 4 Urban 2-Lane Undivided Unsignalized 4-Leg:
Minor AADT vs Fatal+Injury Crashes / Year
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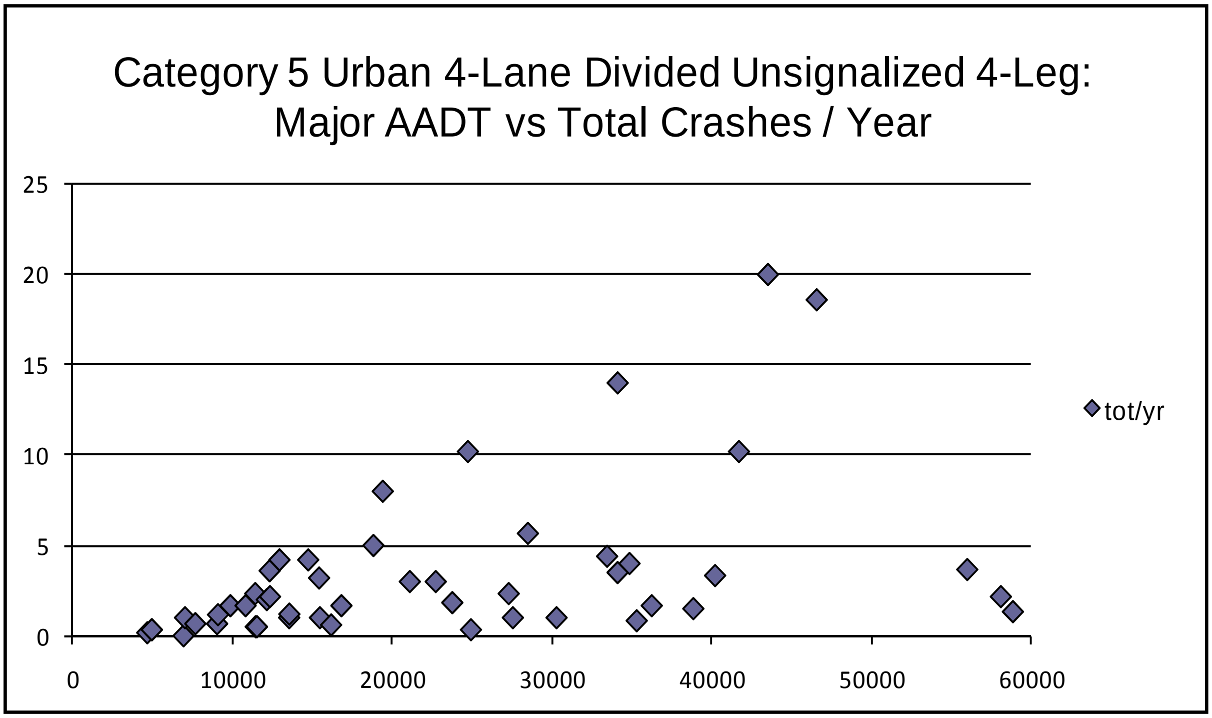
4
3
2
1
0
0
1000
2000
3000
4000
5000
6000
inj/yr



Category 5 Urban 4-Lane Divided Unsignalized 4-Leg:
Major AADT vs Total Crashes / Year
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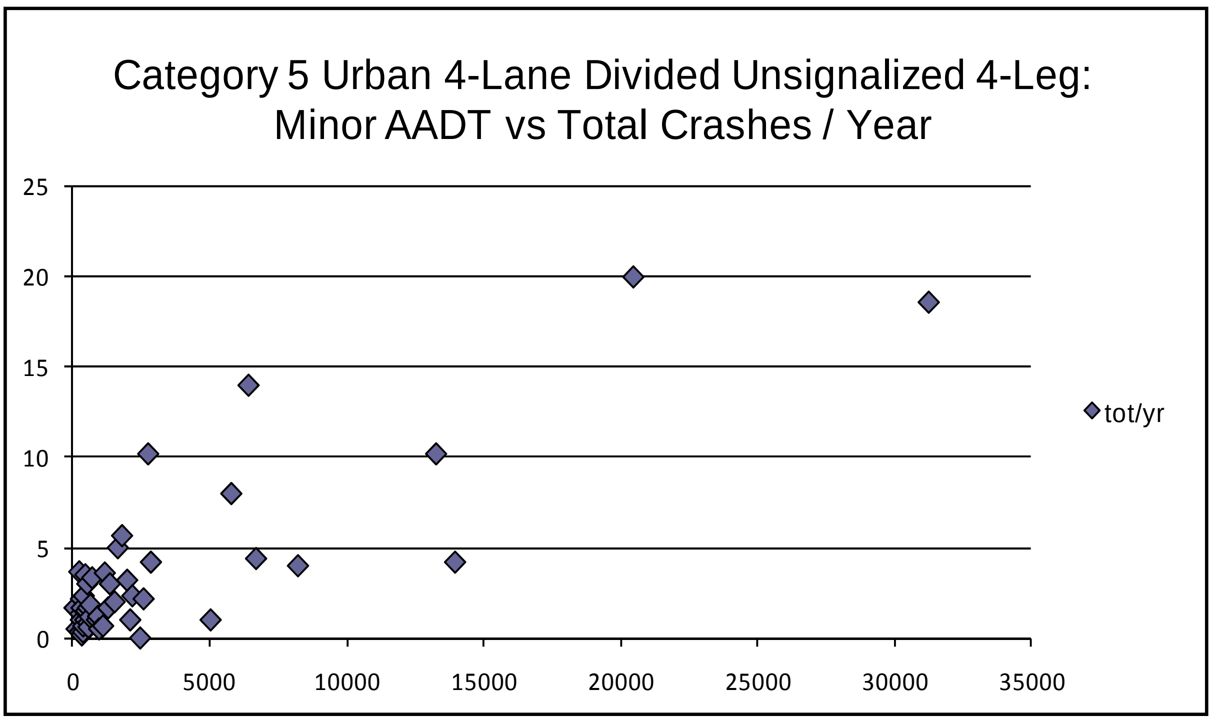
20
15
10
5
0
0
10000
20000
30000
40000
50000
60000
tot/yr



Category 5 Urban 4-Lane Divided Unsignalized 4-Leg:
Minor AADT vs Total Crashes / Year
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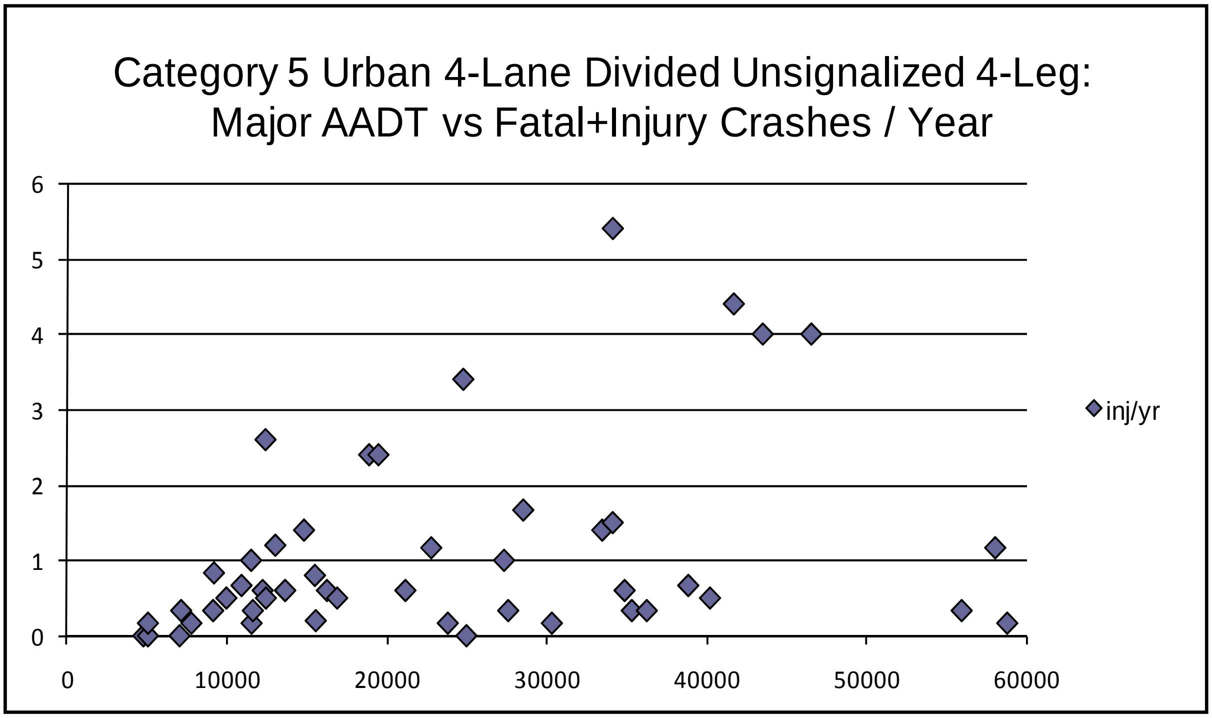
20
15
10
5
0
0
5000
10000
15000
20000
25000
30000
35000
tot/yr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Major AADT vs Fatal+Injury Crashes / Year
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3
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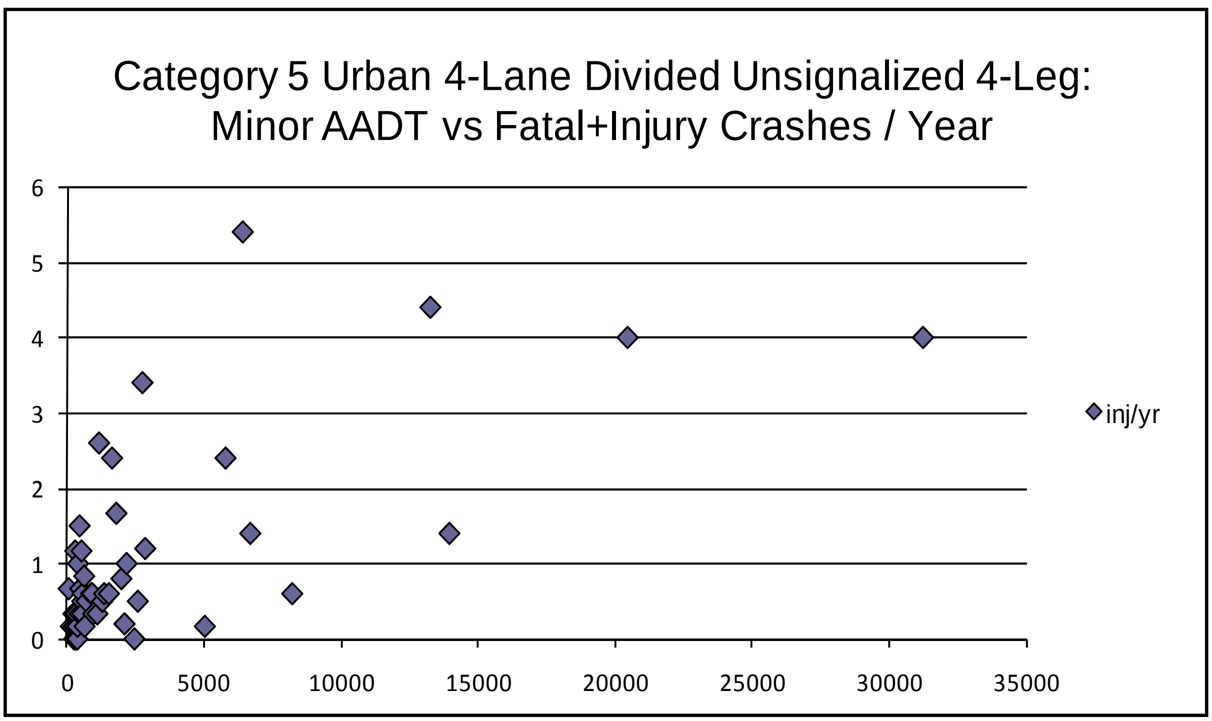
20000
30000
40000
50000
60000
inj/yr


Category 5 Urban 4-Lane Divided Unsignalized 4-Leg:
Minor AADT vs Fatal+Injury Crashes / Year
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5
4
3
2
1
0
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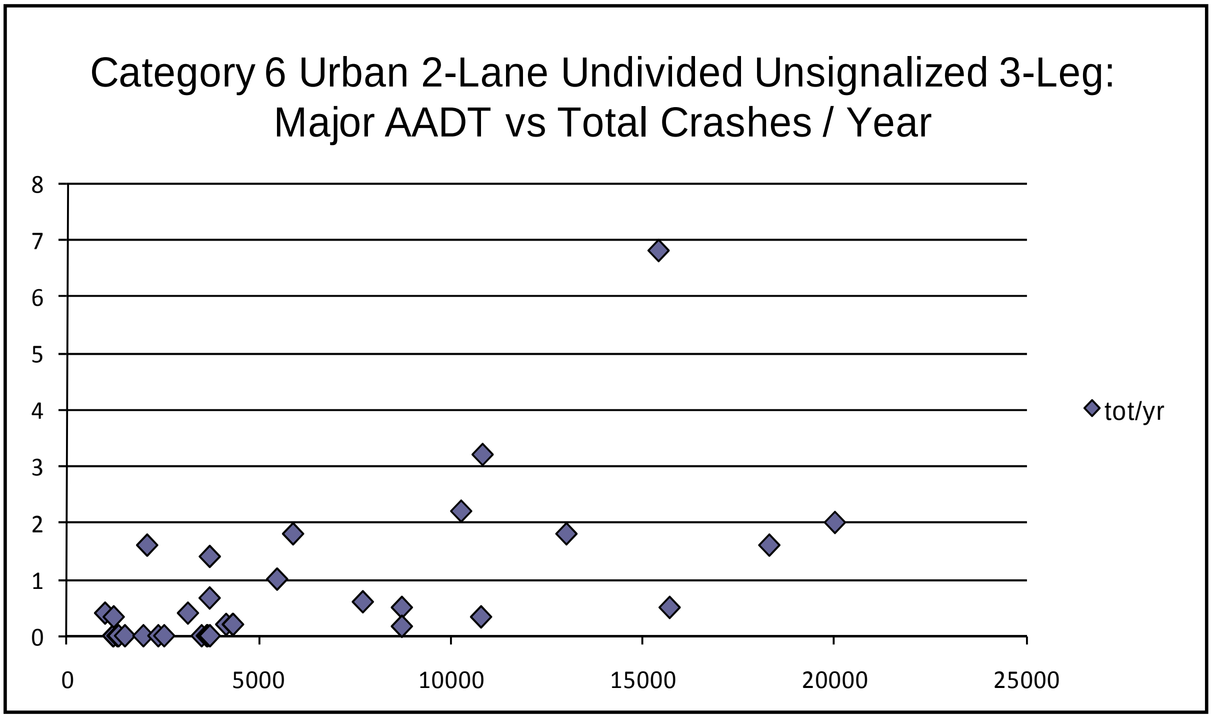
10000
15000
20000
25000
30000
35000
inj/yr


Category 6 Urban 2-Lane Undivided Unsignalized 3-Leg:
Major AADT vs Total Crashes / Year
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7
6
5
4
3
2
1
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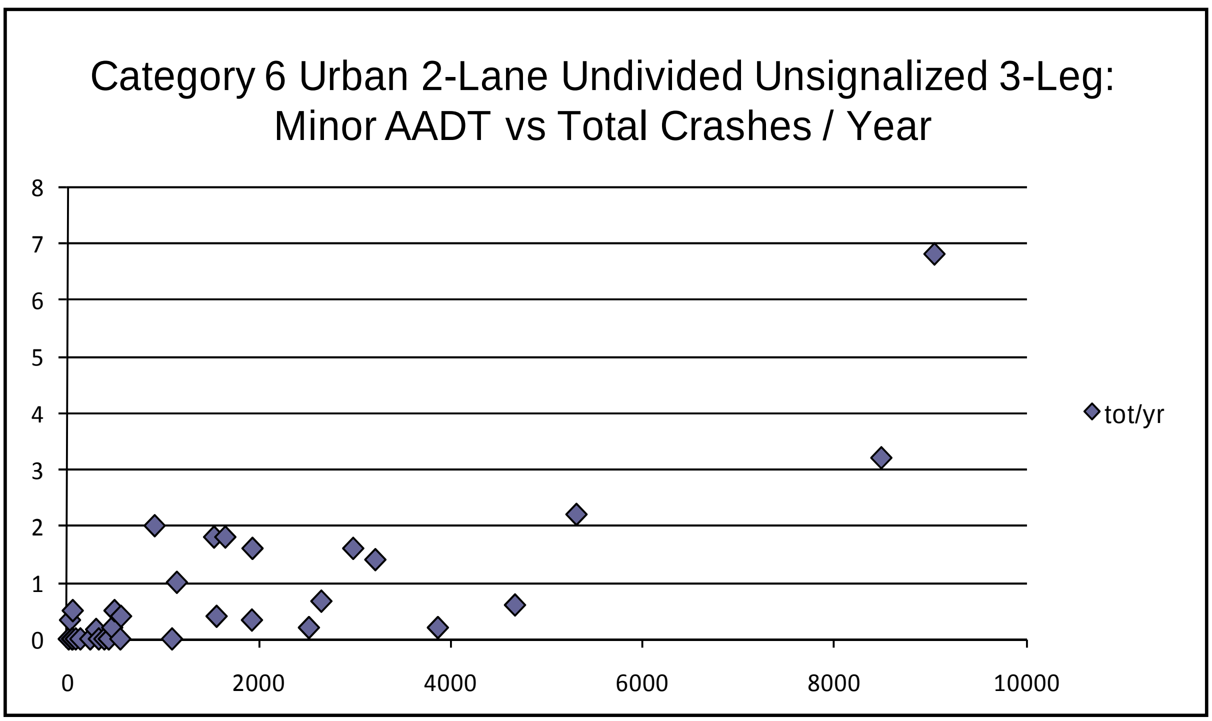
0
5000
10000
15000
20000
25000
tot/yr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Minor AADT vs Total Crashes / Year
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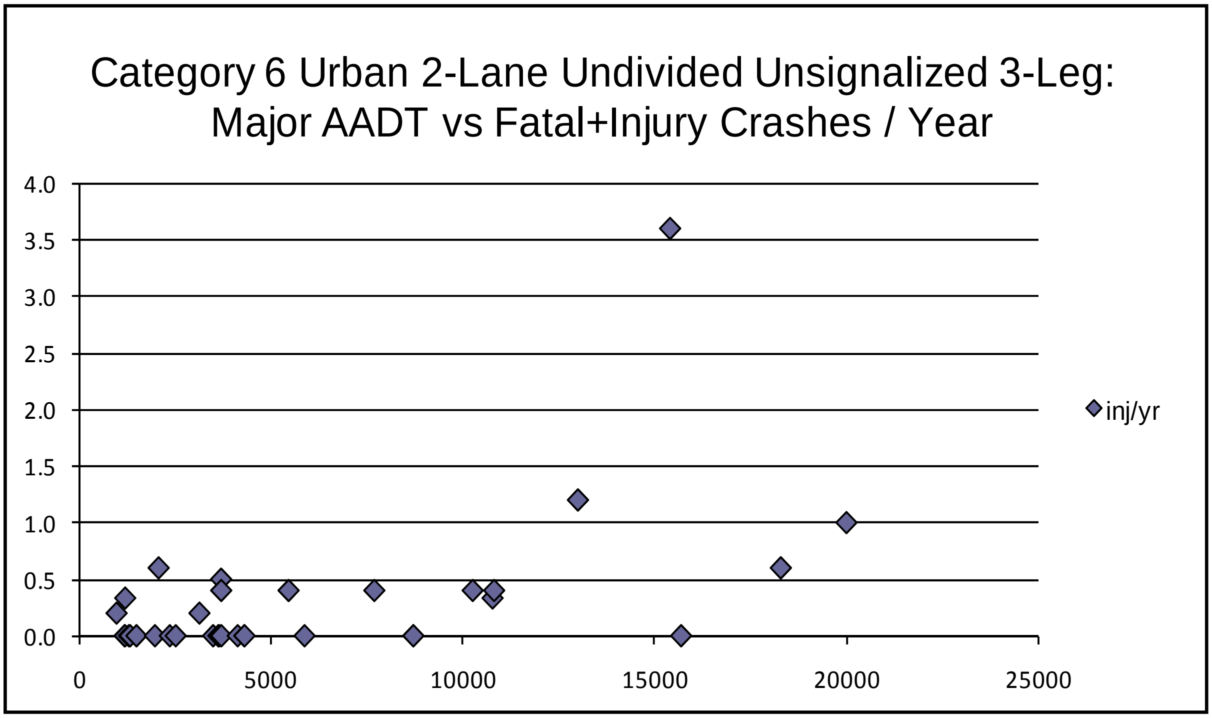
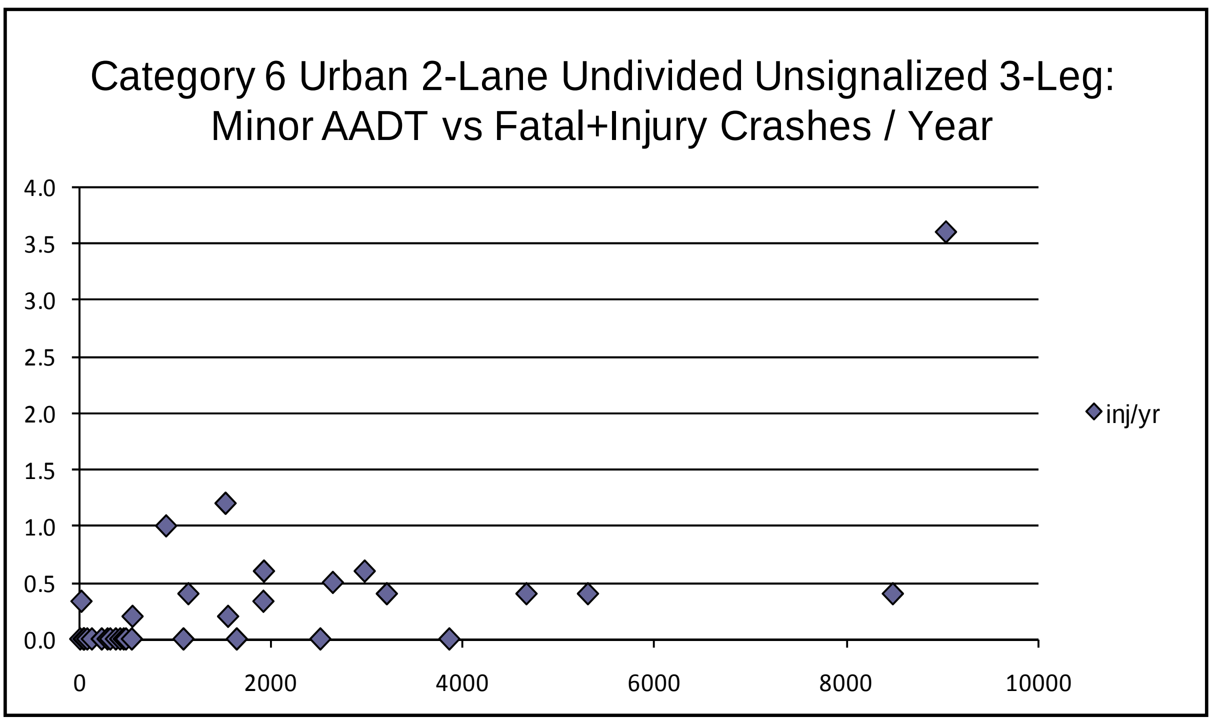
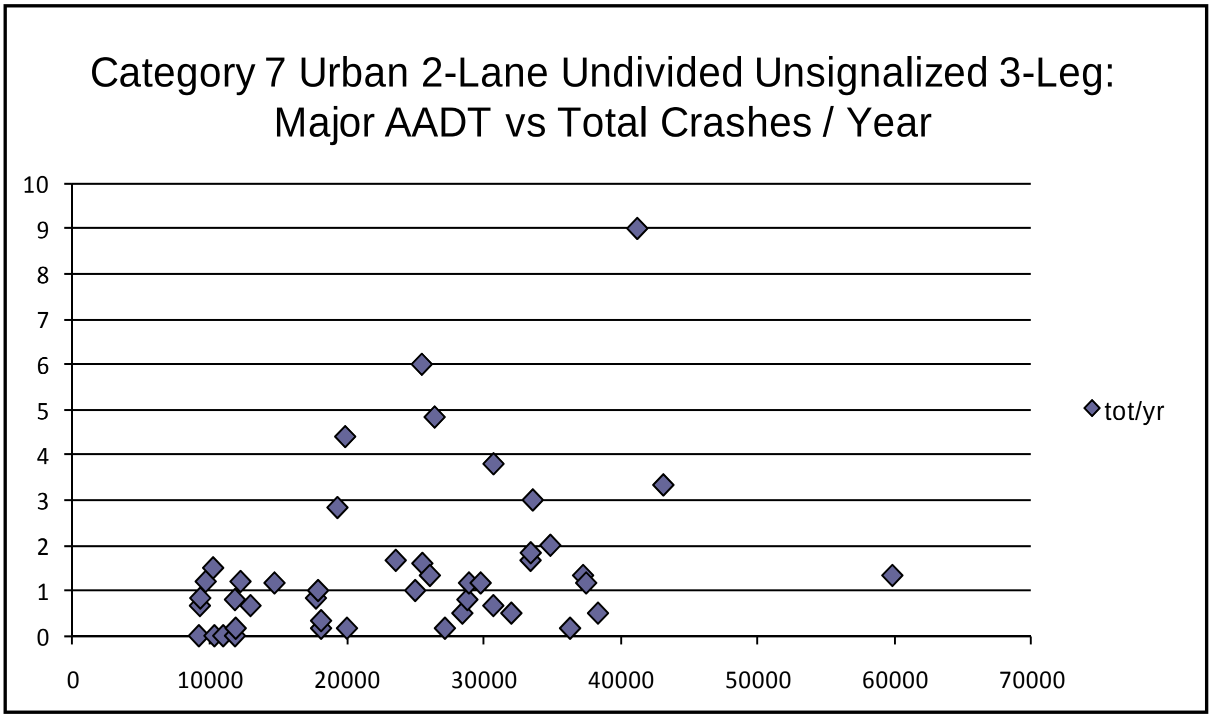
7
6
5
4
3
2
1
0
0
2000
4000
6000
8000
10000
tot/yr


Category 6 Urban 2-Lane Undivided Unsignalized 3-Leg:
Major AADT vs Fatal+Injury Crashes / Year
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5000
10000
15000
20000
25000
inj/yr


Category 6 Urban 2-Lane Undivided Unsignalized 3-Leg:
Minor AADT vs Fatal+Injury Crashes / Year
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2000
4000
6000
8000
10000
inj/yr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Major AADT vs Total Crashes / Year
10
9
8
7
6
5
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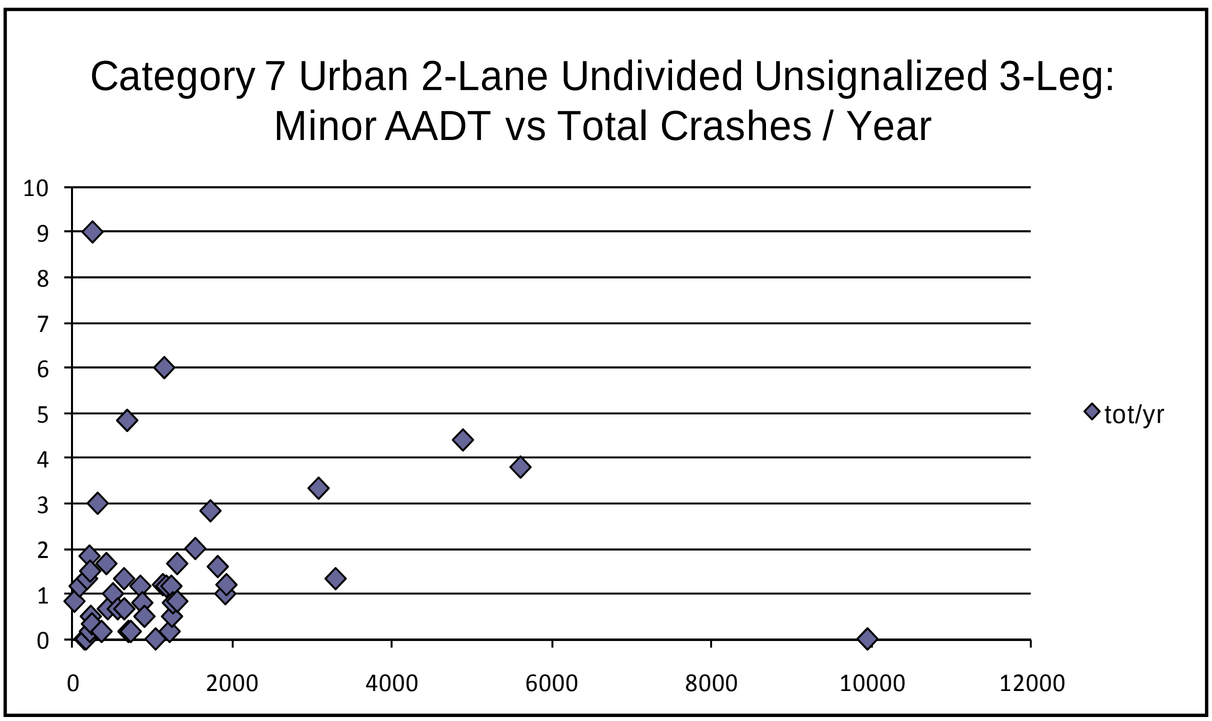
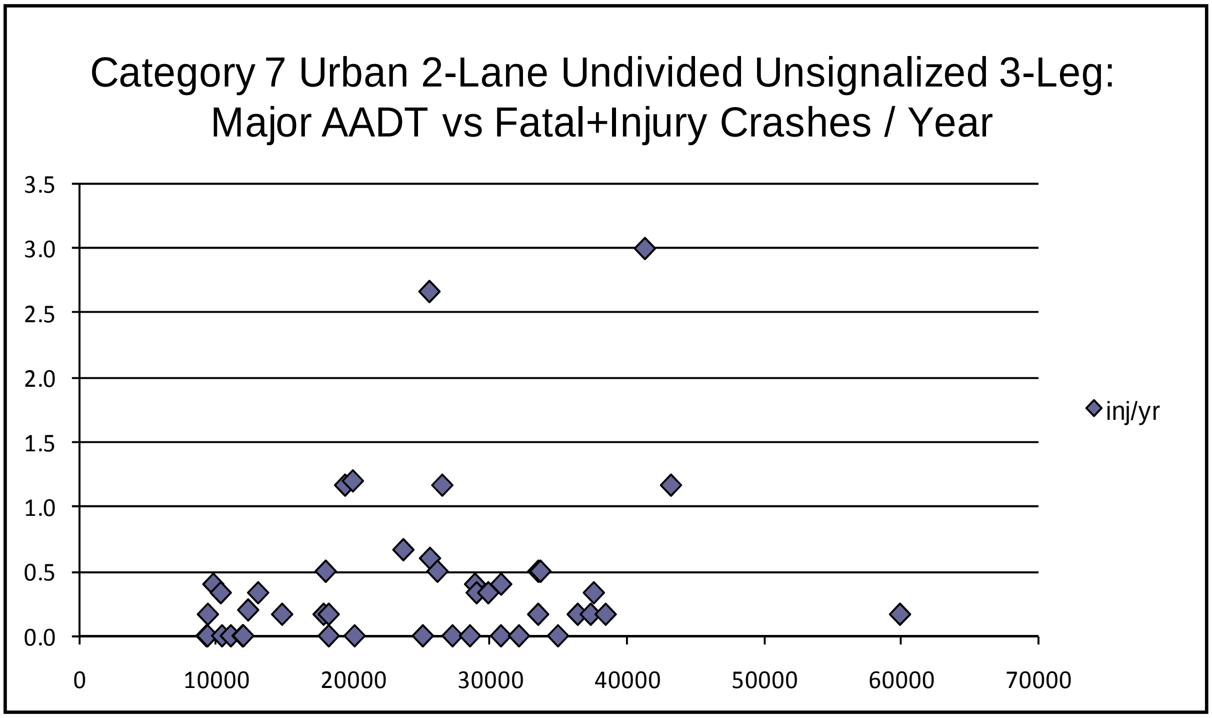
3
2
1
0
0
10000
20000
30000
40000
50000
60000
70000
tot/yr


Category 7 Urban 2-Lane Undivided Unsignalized 3-Leg:
Minor AADT vs Total Crashes / Year
10
9
8
7
6
5
4
3
2
1
0
0
2000
4000
6000
8000
10000
12000
tot/yr


Category 7 Urban 2-Lane Undivided Unsignalized 3-Leg:
Major AADT vs Fatal+Injury Crashes / Year
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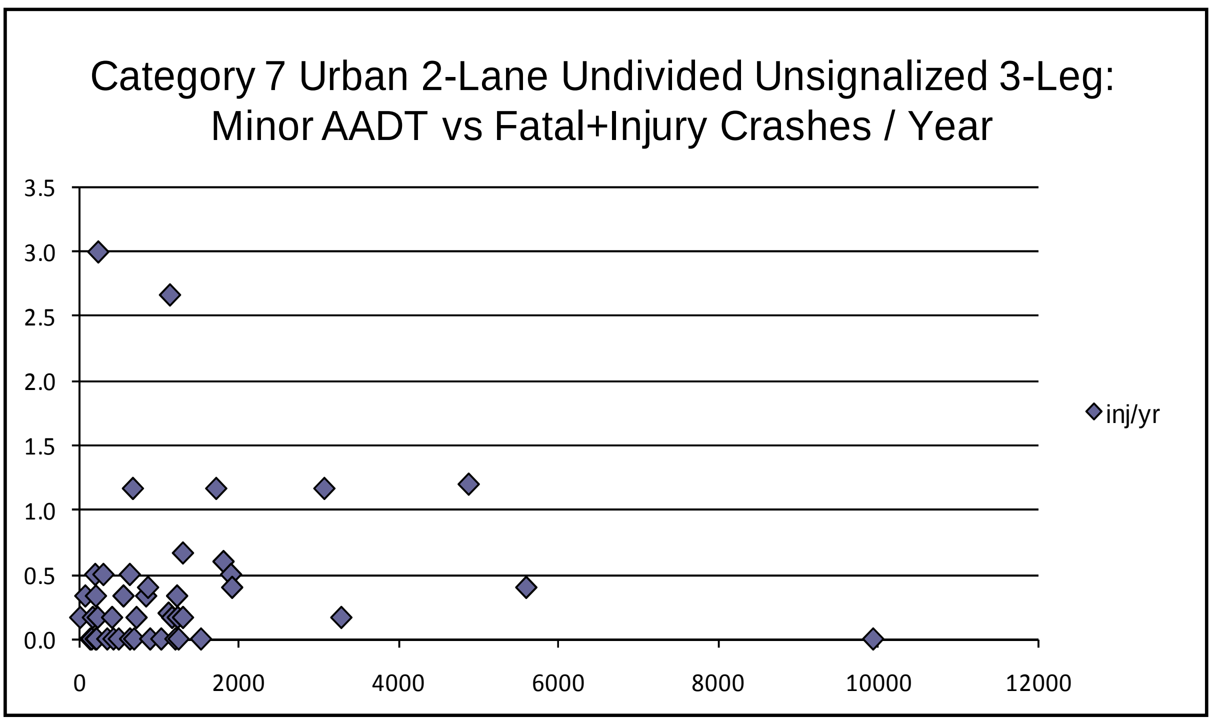
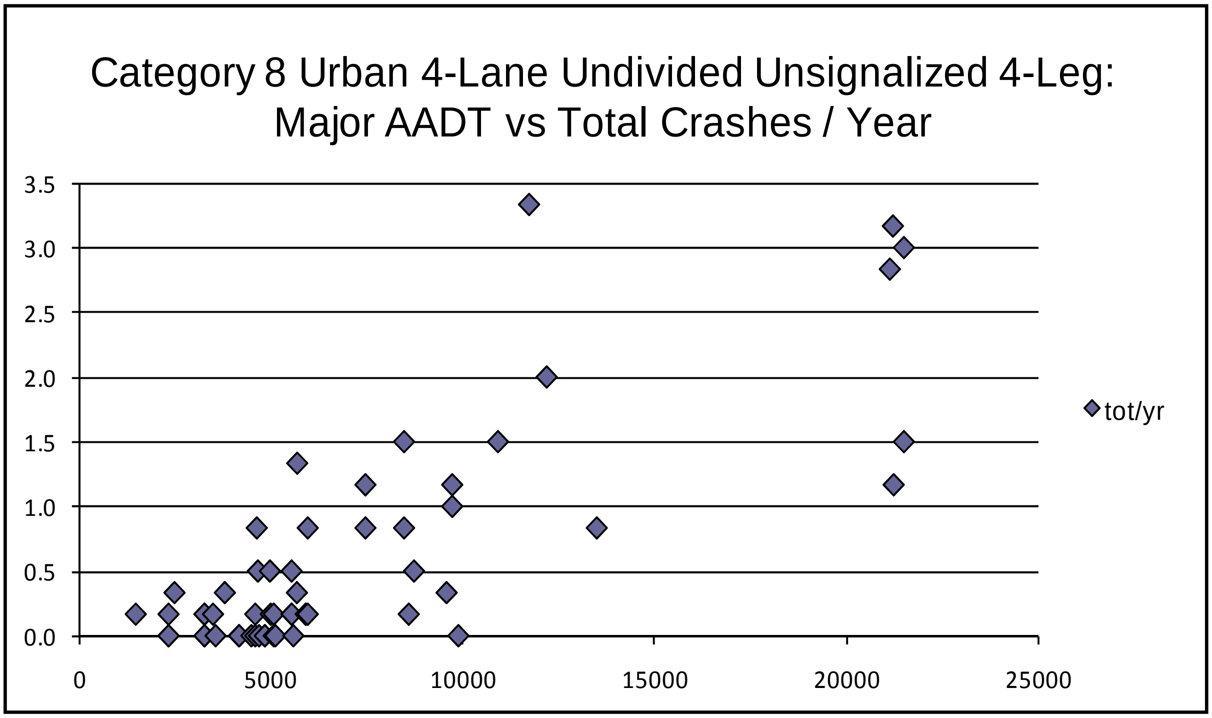
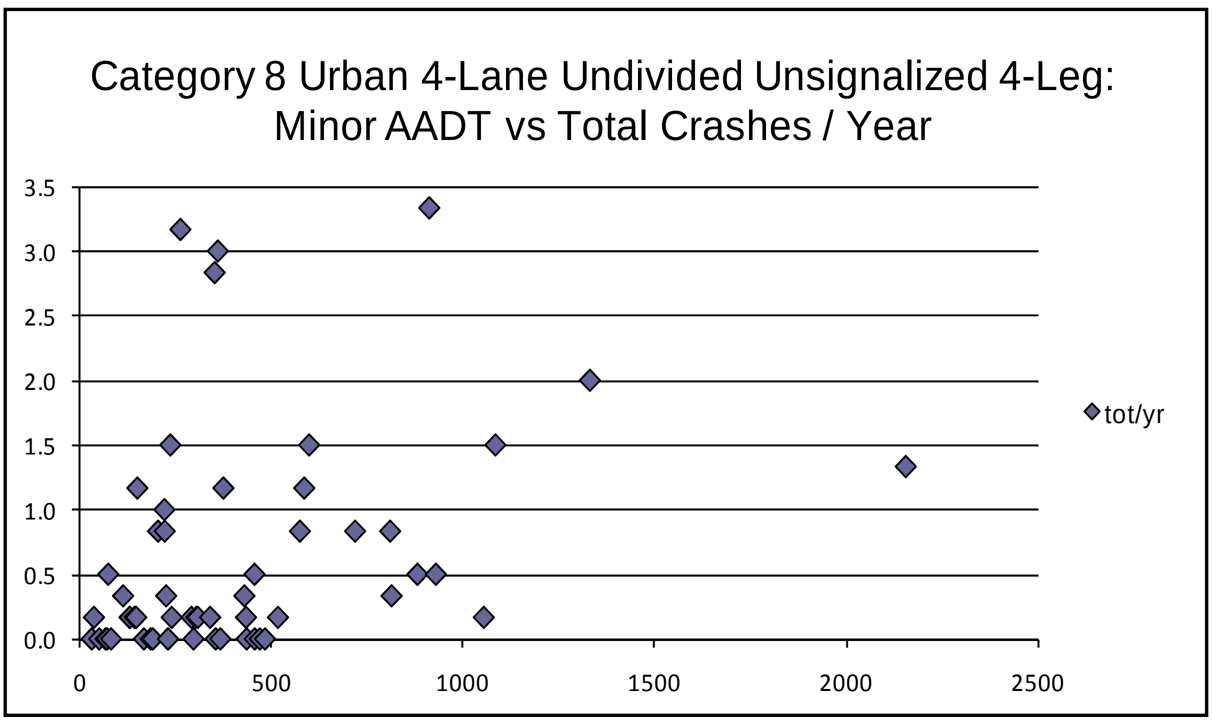
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10000
20000
30000
40000
50000
60000
70000
inj/yr


Category 7 Urban 2-Lane Undivided Unsignalized 3-Leg:
Minor AADT vs Fatal+Injury Crashes / Year
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2000
4000
6000
8000
10000
12000
inj/yr



Category 8 Urban 4-Lane Undivided Unsignalized 4-Leg:
Major AADT vs Total Crashes / Year
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5000
10000
15000
20000
25000
tot/yr



Category 8 Urban 4-Lane Undivided Unsignalized 4-Leg:
Minor AADT vs Total Crashes / Year
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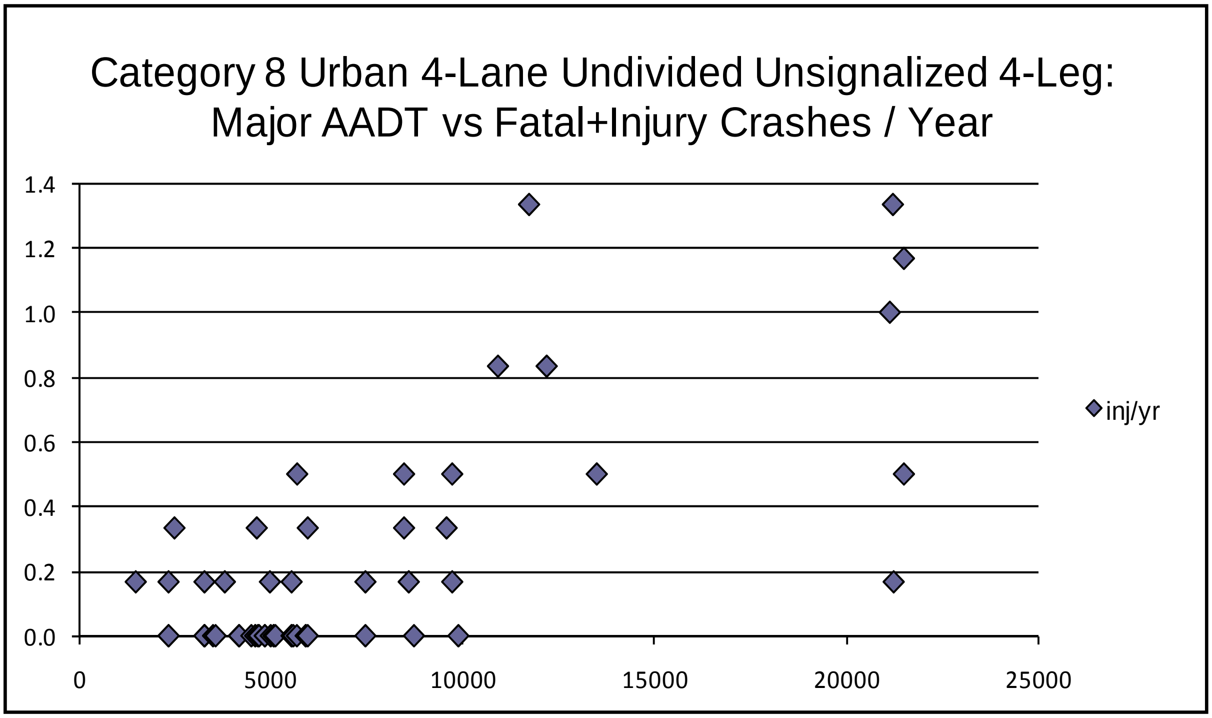
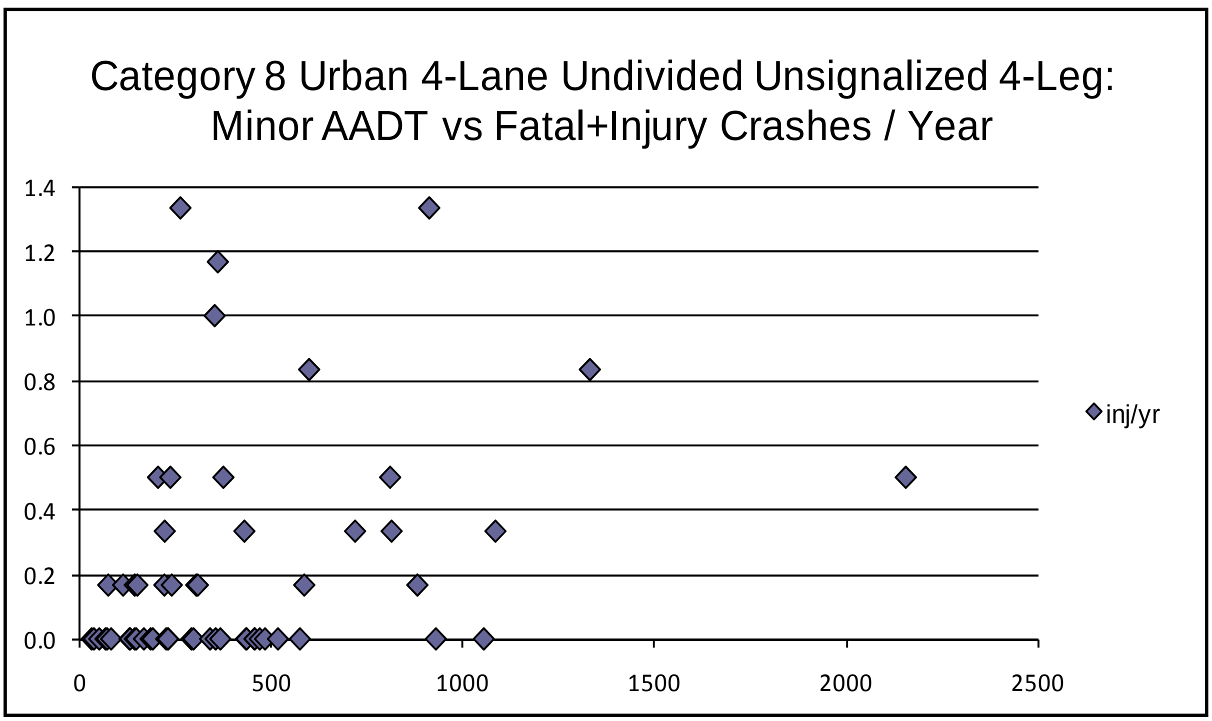
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
500
1000
1500
2000
2500
tot/yr


Category 8 Urban 4-Lane Undivided Unsignalized 4-Leg:
Major AADT vs Fatal+Injury Crashes / Year
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5000
10000
15000
20000
25000
inj/yr


Category 8 Urban 4-Lane Undivided Unsignalized 4-Leg:
Minor AADT vs Fatal+Injury Crashes / Year
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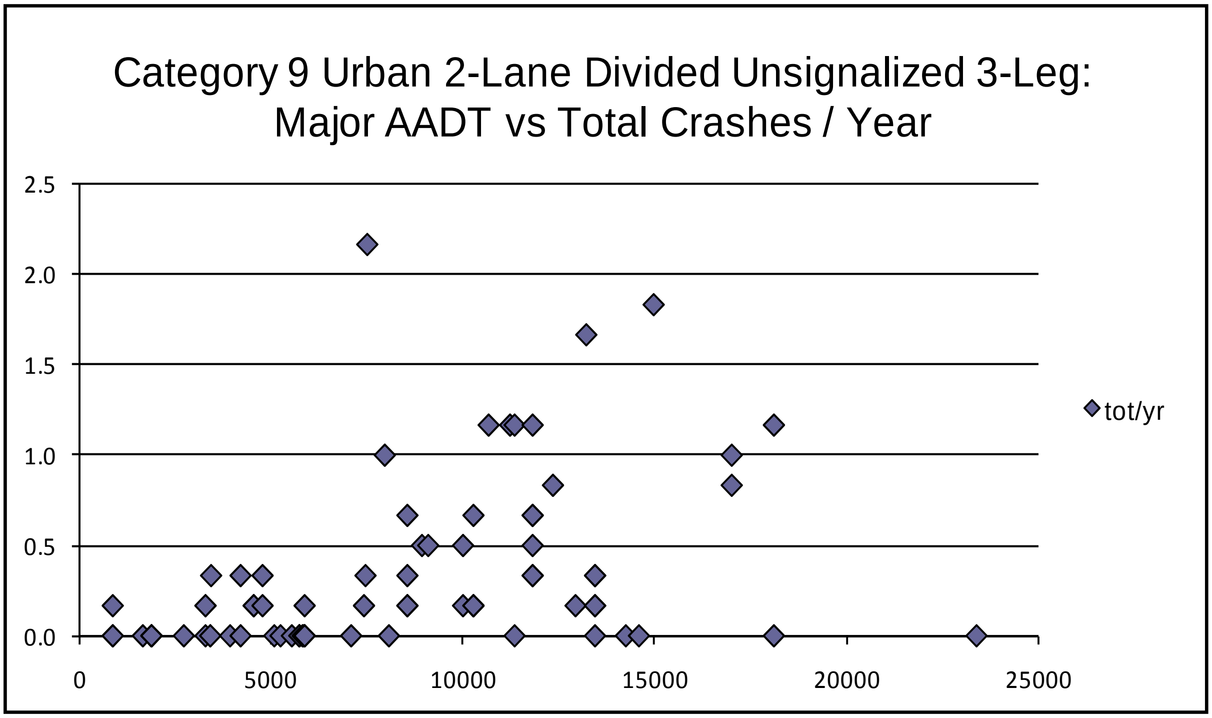
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
500
1000
1500
2000
2500
inj/yr


Category 9 Urban 2-Lane Divided Unsignalized 3-Leg:
Major AADT vs Total Crashes / Year
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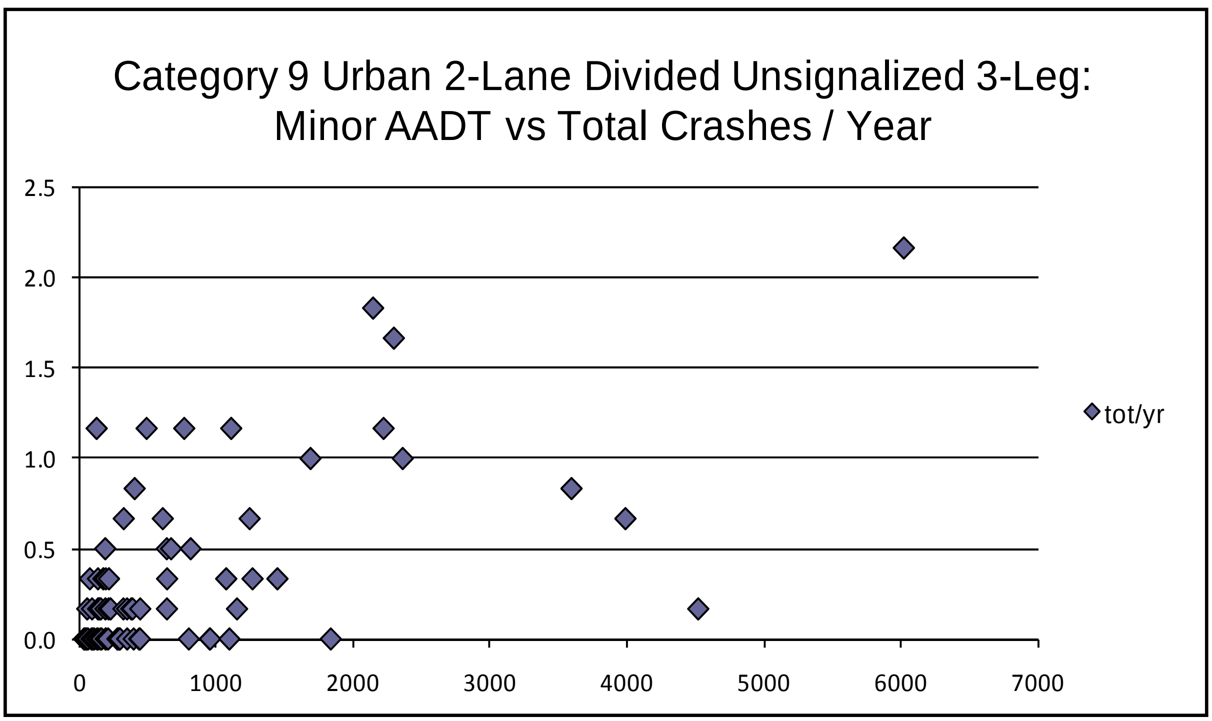
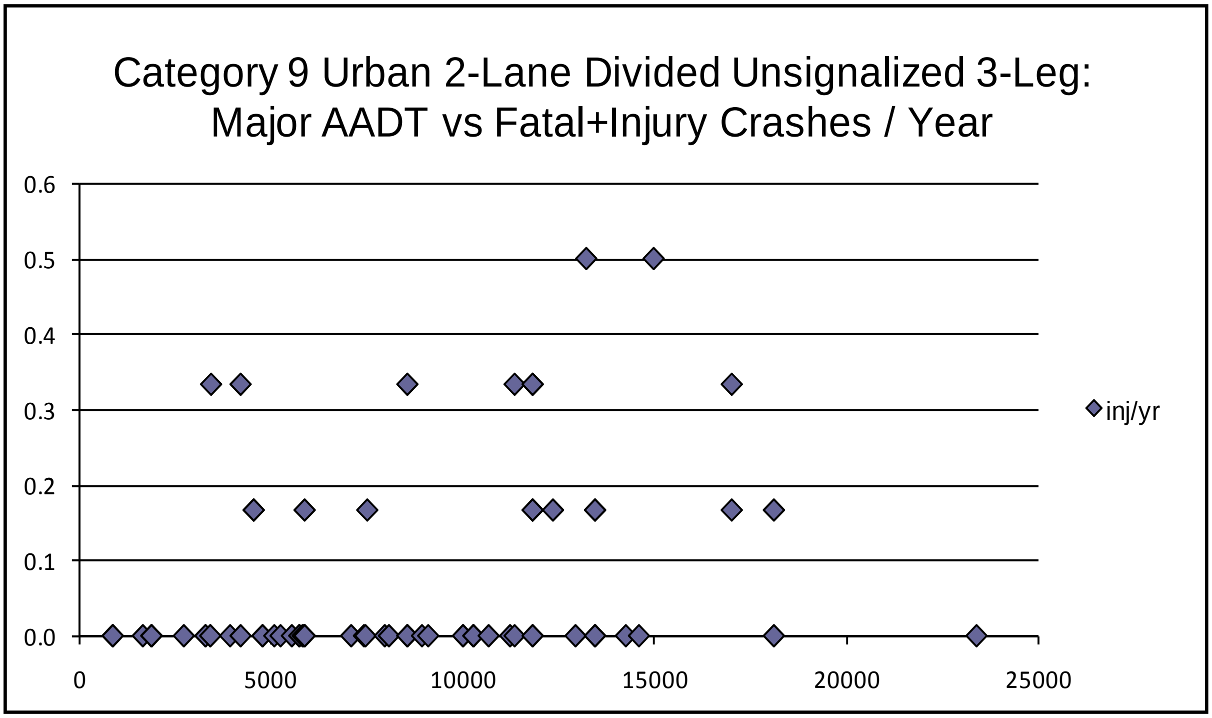
2.0
1.5
1.0
0.5
0.0
0
5000
10000
15000
20000
25000
tot/yr


Category 9 Urban 2-Lane Divided Unsignalized 3-Leg:
Minor AADT vs Total Crashes / Year
2.5
2.0
1.5
1.0
0.5
0.0
0
1000
2000
3000
4000
5000
6000
7000
tot/yr


Category 9 Urban 2-Lane Divided Unsignalized 3-Leg:
Major AADT vs Fatal+Injury Crashes / Year
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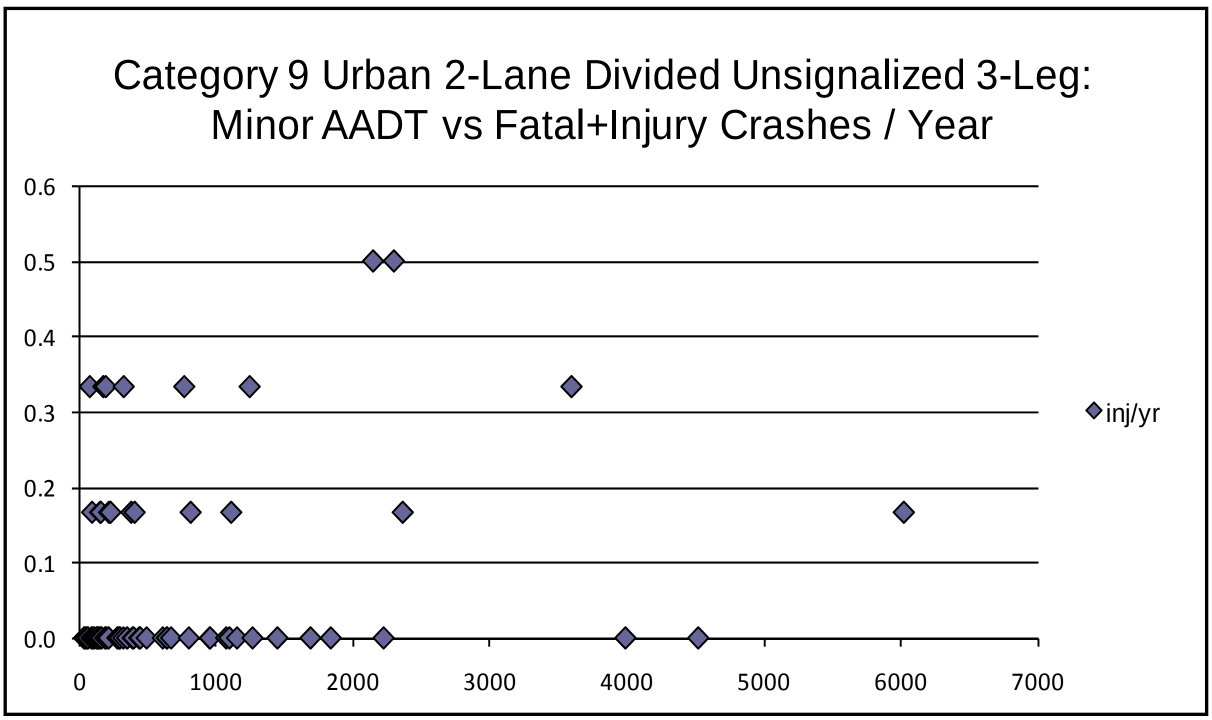
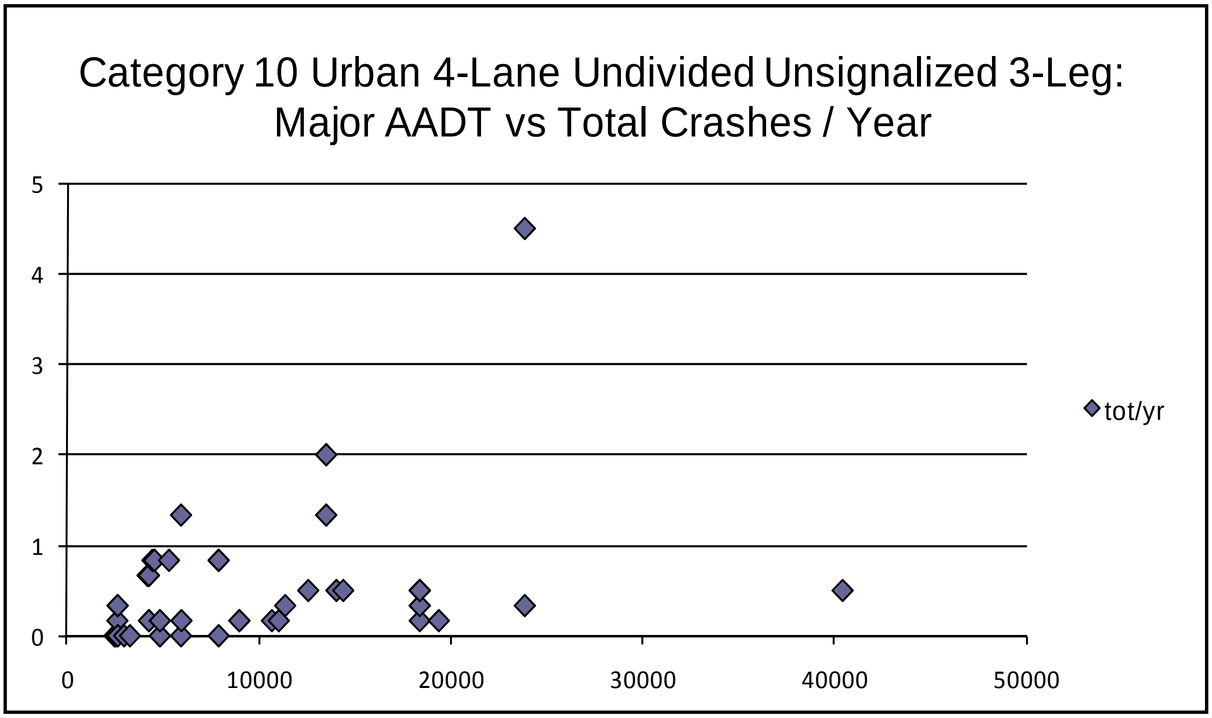
0.5
0.4
0.3
0.2
0.1
0.0
0
5000
10000
15000
20000
25000
inj/yr


Category 9 Urban 2-Lane Divided Unsignalized 3-Leg:
Minor AADT vs Fatal+Injury Crashes / Year
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1000
2000
3000
4000
5000
6000
7000
inj/yr


Category 10 Urban 4-Lane Undivided Unsignalized 3-Leg:
Major AADT vs Total Crashes / Year
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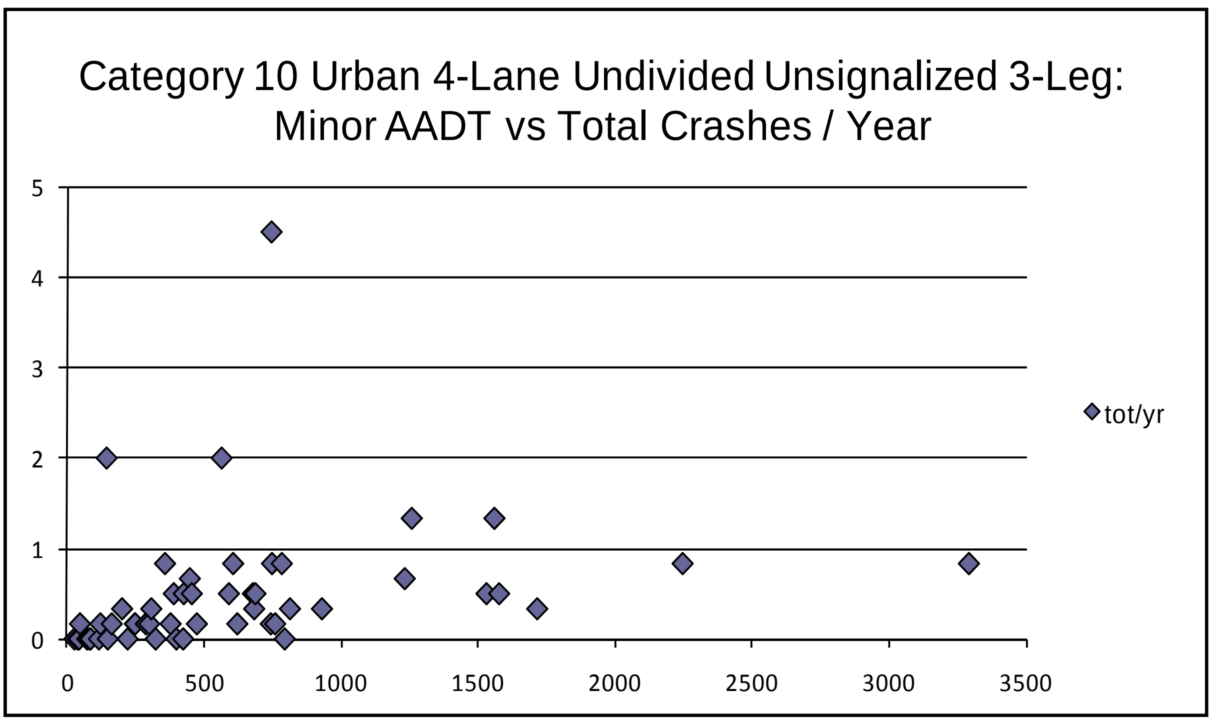
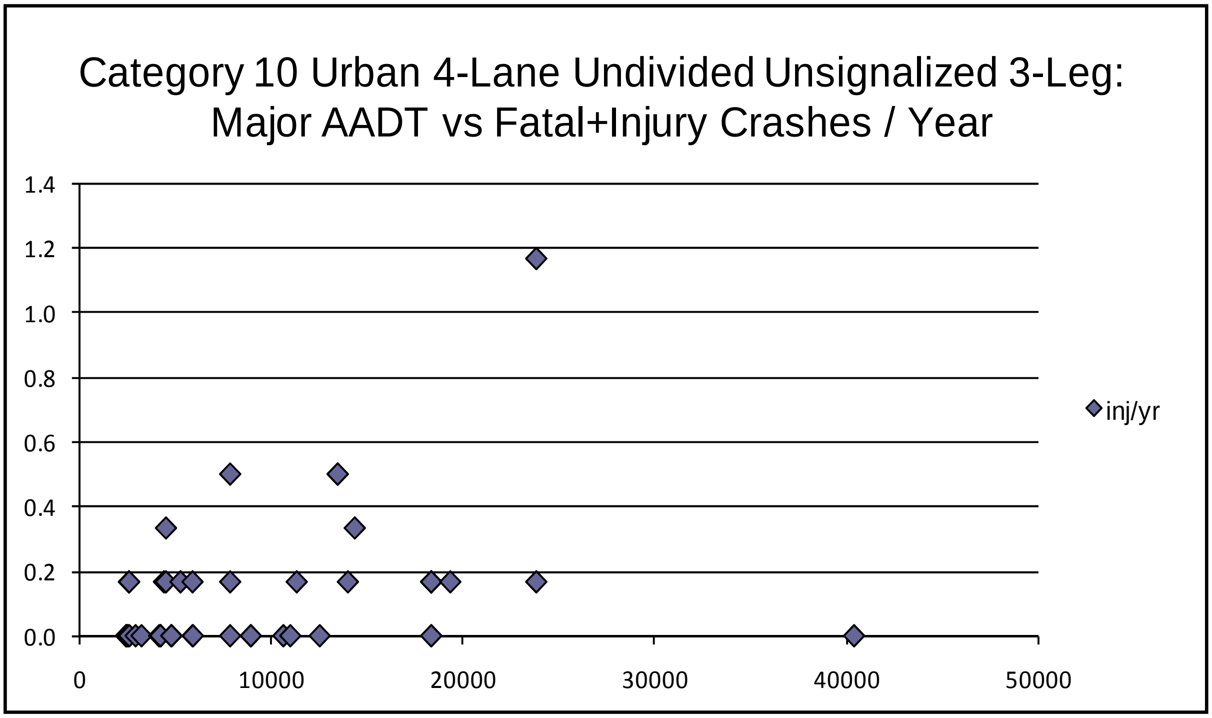
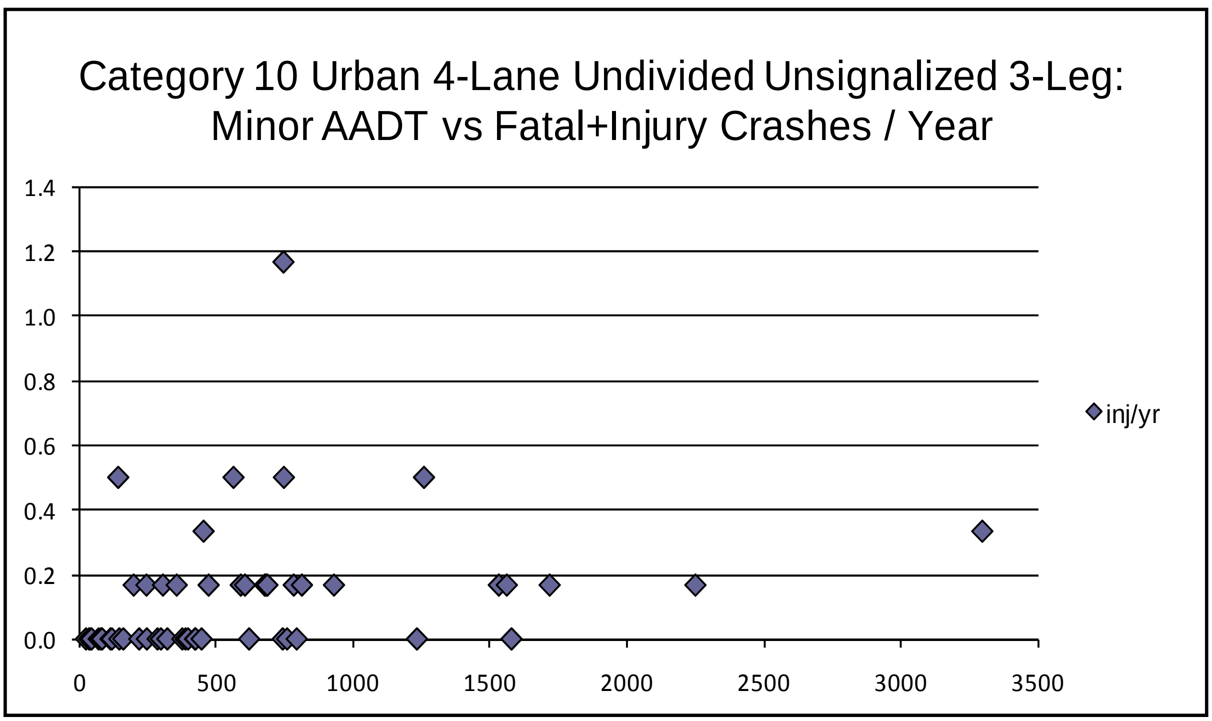
4
3
2
1
0
0
10000
20000
30000
40000
50000
tot/yr

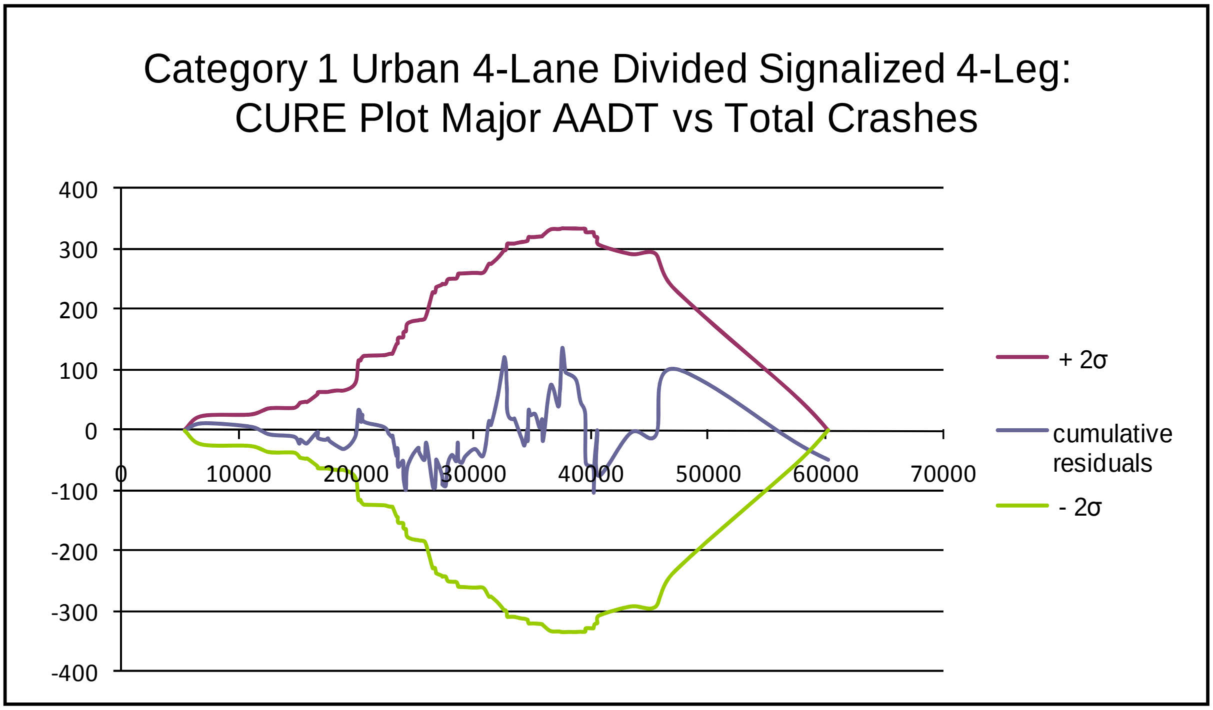

Category 10 Urban 4-Lane Undivided Unsignalized 3-Leg:
Minor AADT vs Total Crashes / Year
5
4
3
2
1
0
0
500
1000
1500
2000
2500
3000
3500
tot/yr

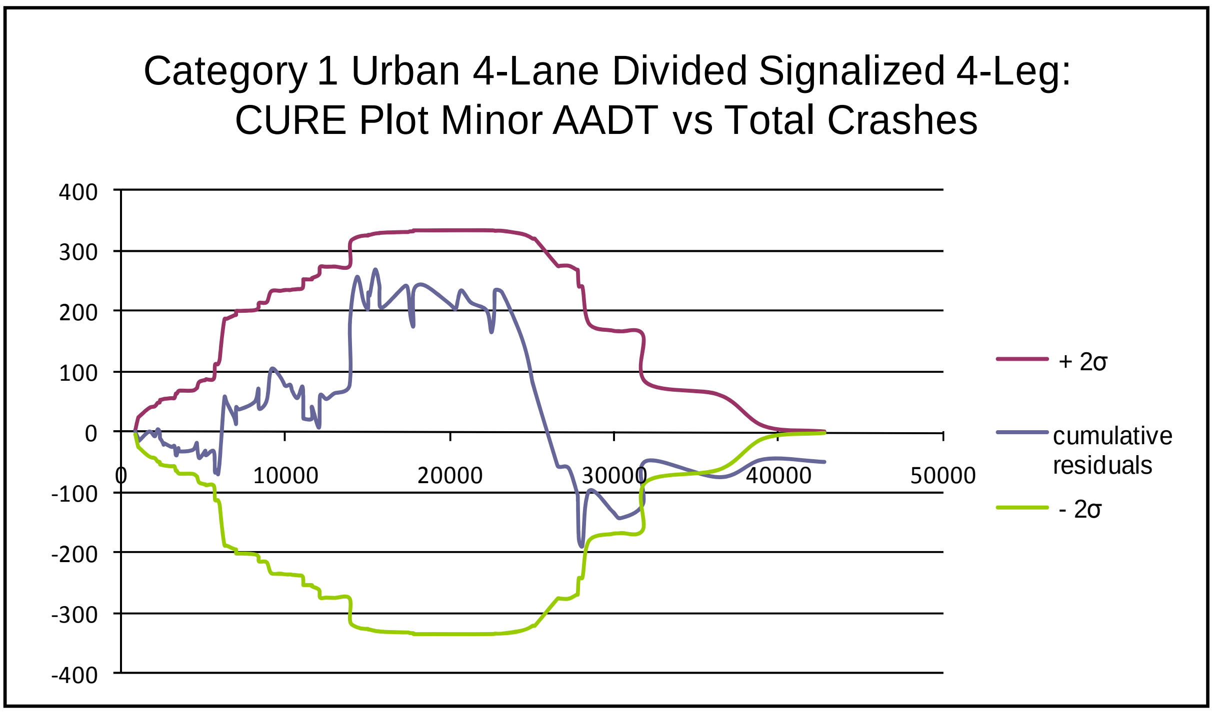

Category 10 Urban 4-Lane Undivided Unsignalized 3-Leg:
Major AADT vs Fatal+Injury Crashes / Year
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10000
20000
30000
40000
50000
inj/yr

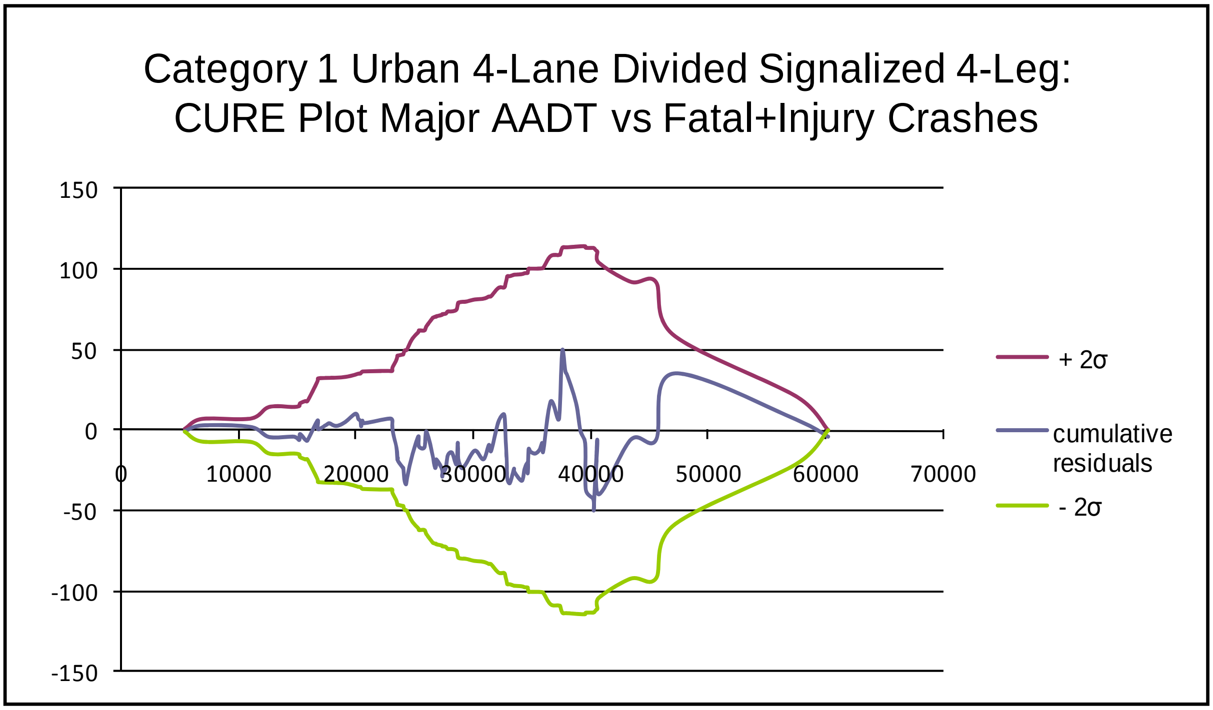

Category 10 Urban 4-Lane Undivided Unsignalized 3-Leg:
Minor AADT vs Fatal+Injury Crashes / Year
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
500
1000
1500
2000
2500
3000
3500
inj/yr

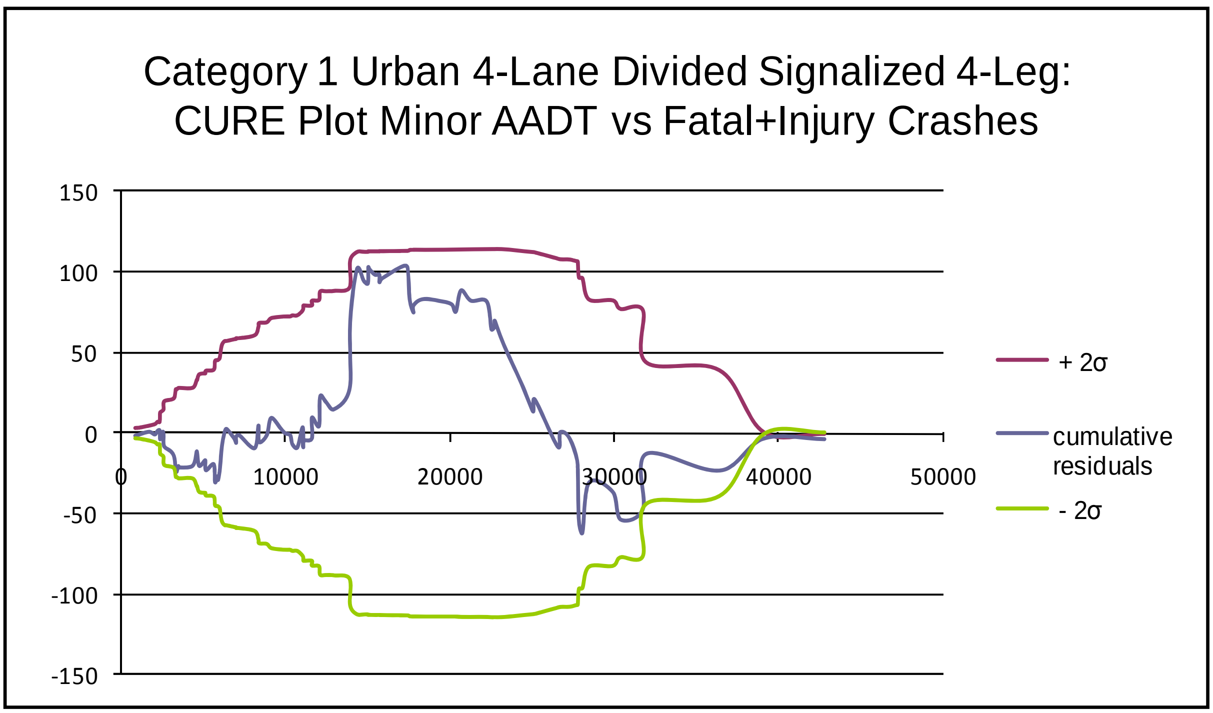
APPENDIX B

CURE PLOTS

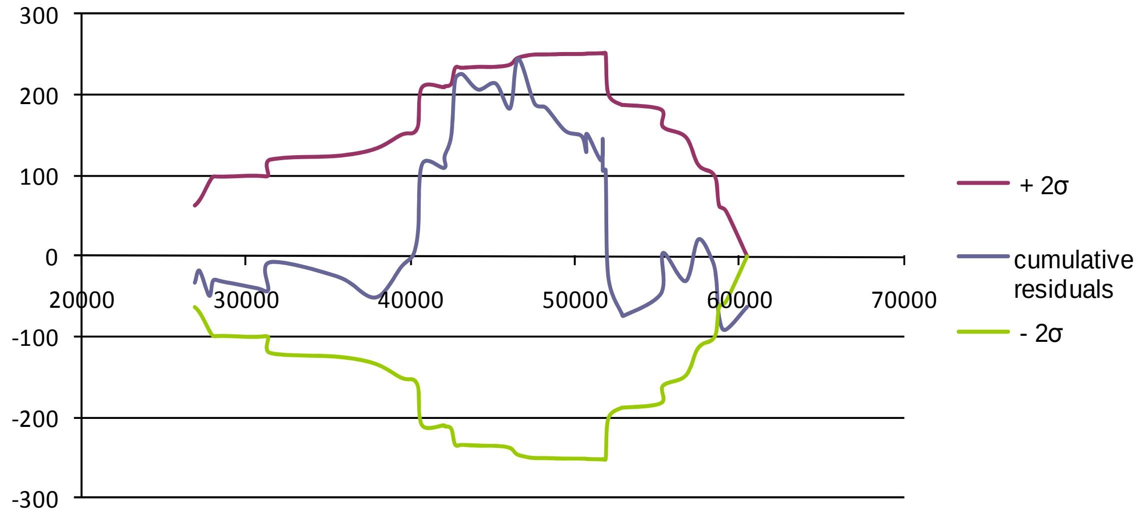

Category 1 Urban 4-Lane Divided Signalized 4-Leg:
CURE Plot Major AADT vs Total Crashes
400
300
200
100
0
-100
-200
-300
-400
0
10000
20000
30000
40000
50000
60000
70000
+ 2σ
cumulative residuals
- 2σ


Category 1 Urban 4-Lane Divided Signalized 4-Leg:
CURE Plot Minor AADT vs Total Crashes
400
300
200
100
0
-100
-200
-300
-400
0
10000
20000
30000
40000
50000
+ 2σ
cumulative residuals
- 2σ

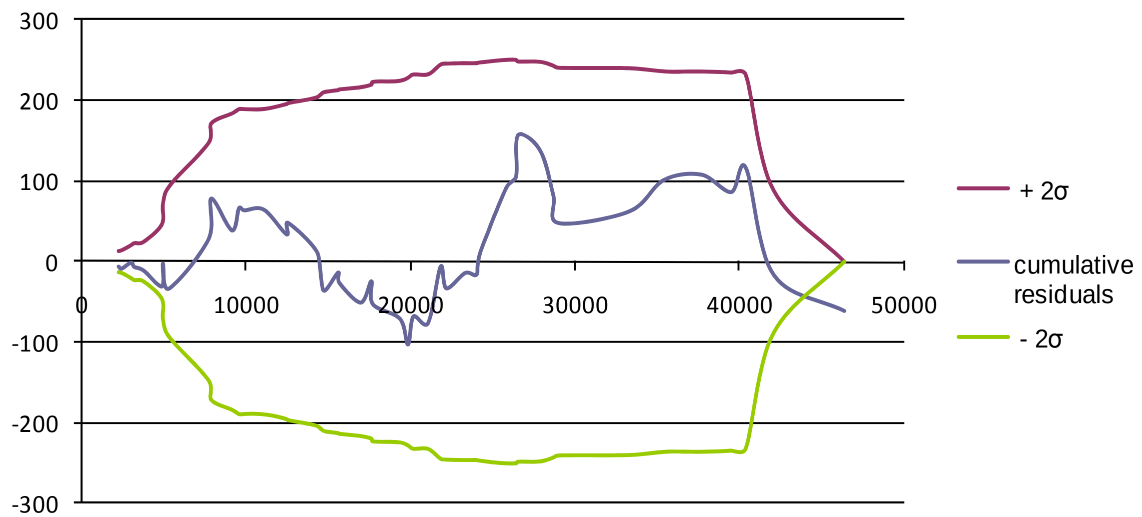

Category 1 Urban 4-Lane Divided Signalized 4-Leg:
CURE Plot Major AADT vs Fatal+Injury Crashes
150
100
50
0
-50
-100
-150
0
10000
20000
30000
40000
50000
60000
70000
+ 2σ
cumulative residuals
- 2σ

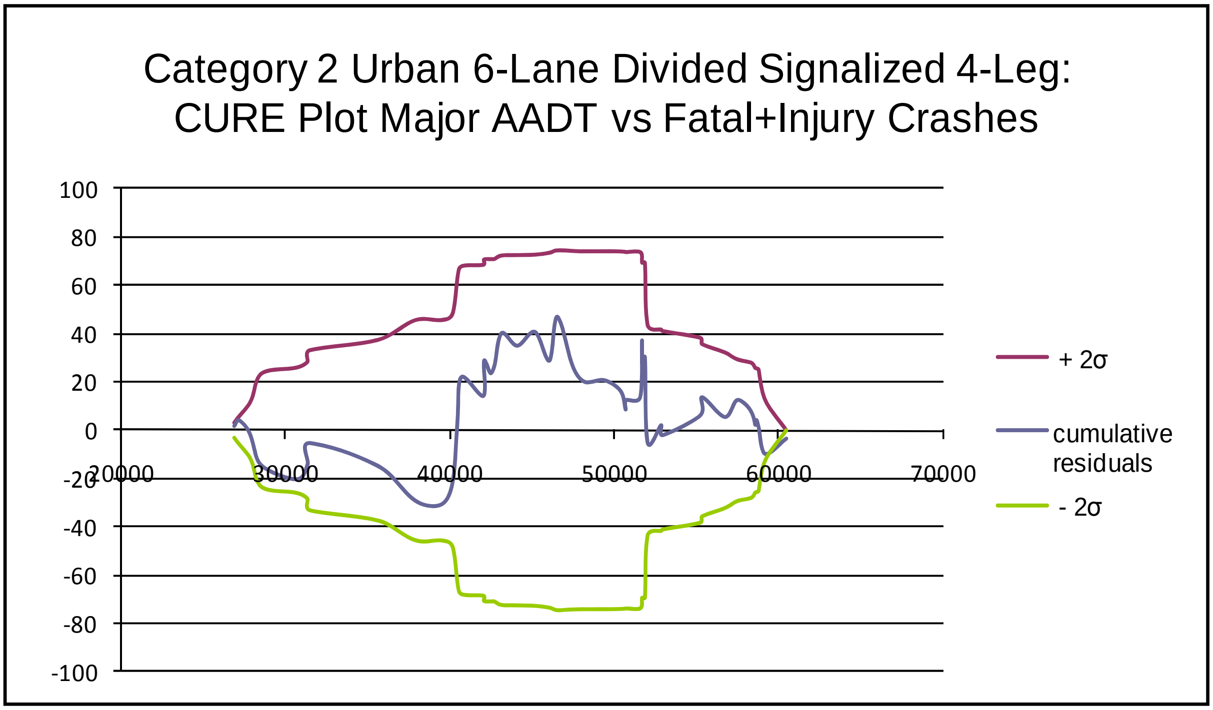

Category 1 Urban 4-Lane Divided Signalized 4-Leg:
CURE Plot Minor AADT vs Fatal+Injury Crashes
150
100
50
0
-50
-100
-150
0
10000
20000
30000
40000
50000
+ 2σ
cumulative residuals
- 2σ

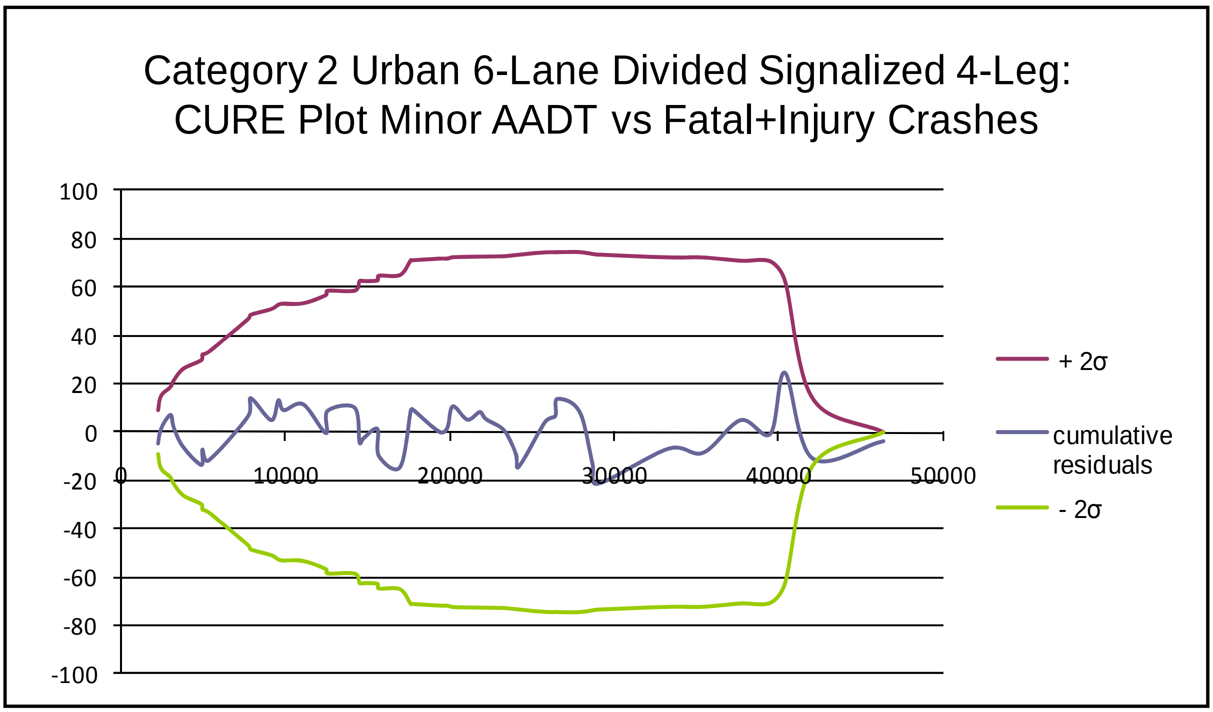
Category 2 Urban 6-Lane Divided Signalized 4-Leg:
CURE Plot Major AADT vs Total Crashes

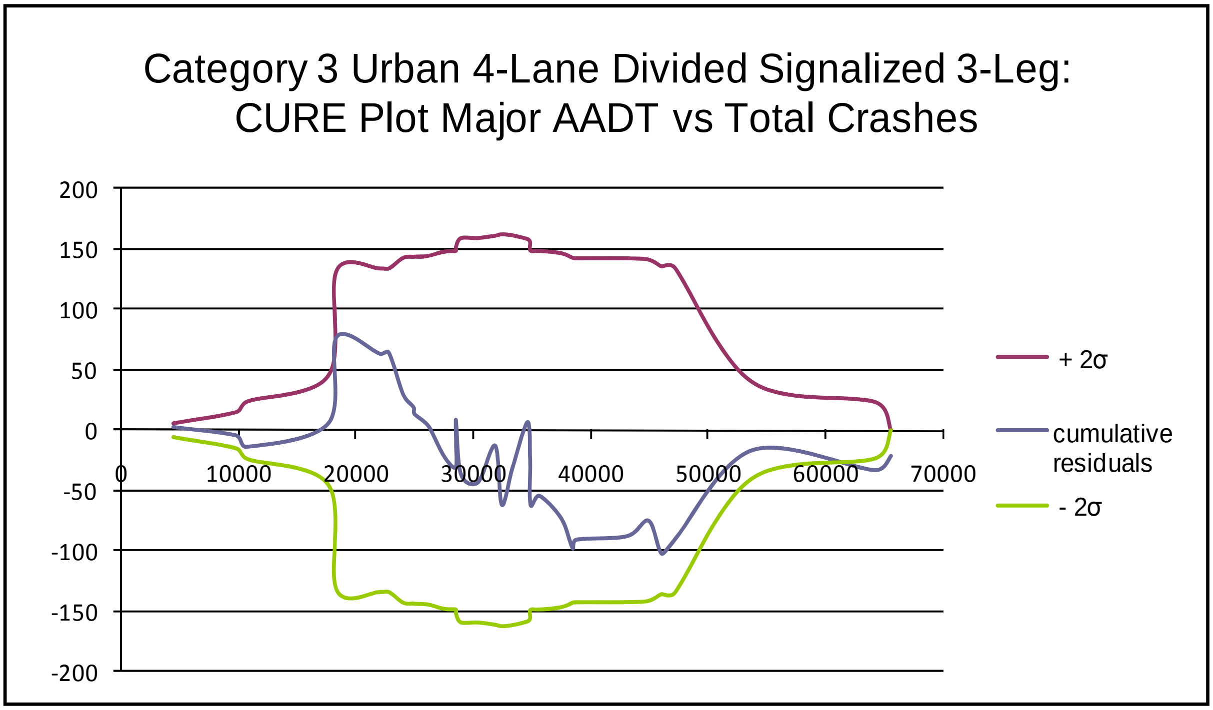


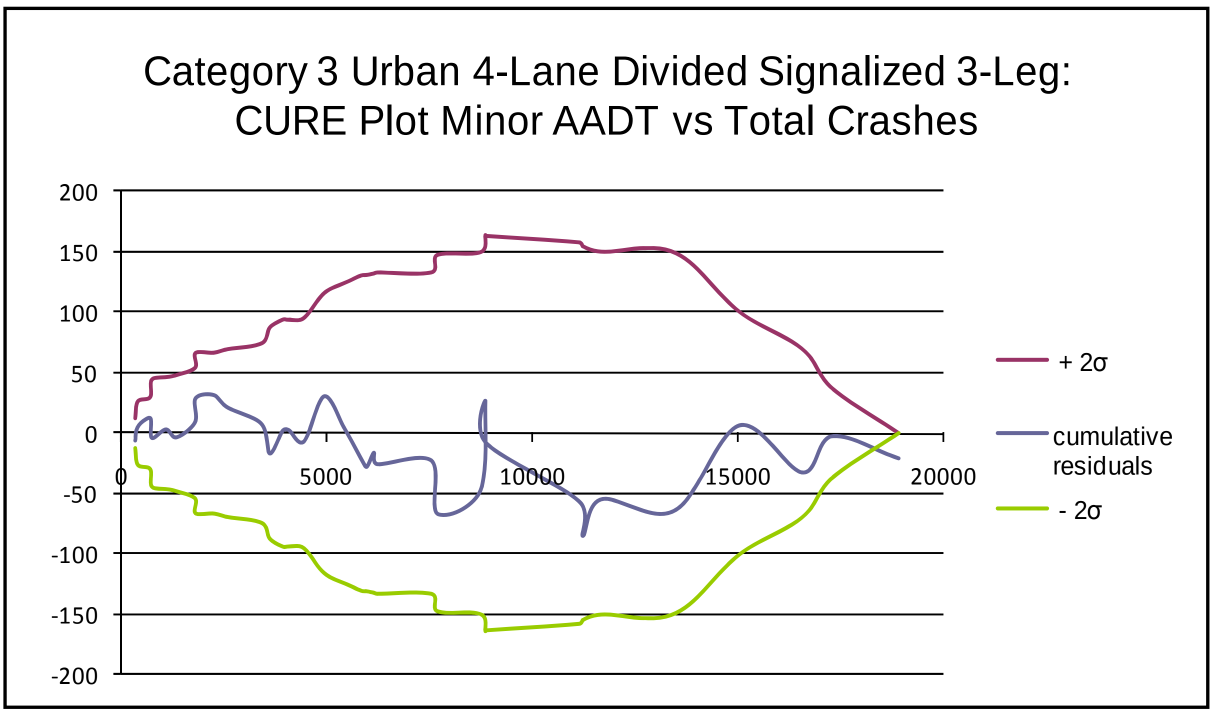
Category 2 Urban 6-Lane Divided Signalized 4-Leg:
CURE Plot Minor AADT vs Total Crashes

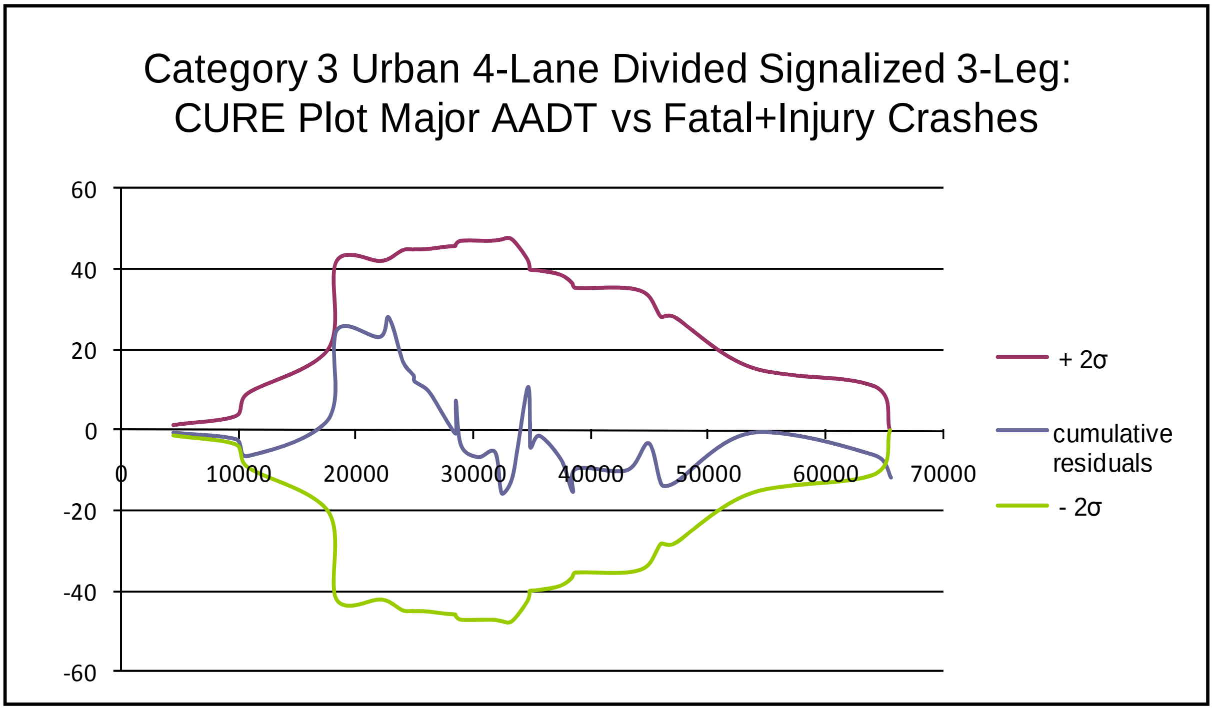


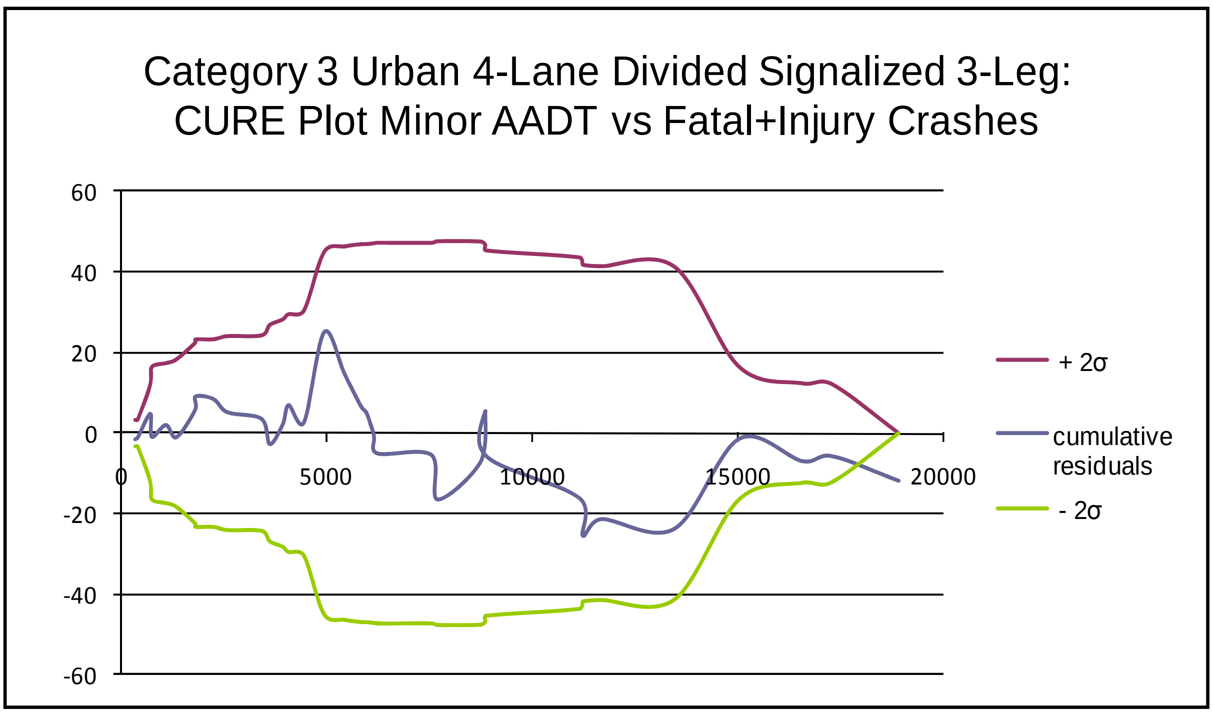

Category 2 Urban 6-Lane Divided Signalized 4-Leg:
CURE Plot Major AADT vs Fatal+Injury Crashes
100
80
60
40
20
0
-20
-40
-60
-80
-100
20000
30000
40000
50000
60000
70000
+ 2σ
cumulative residuals
- 2σ

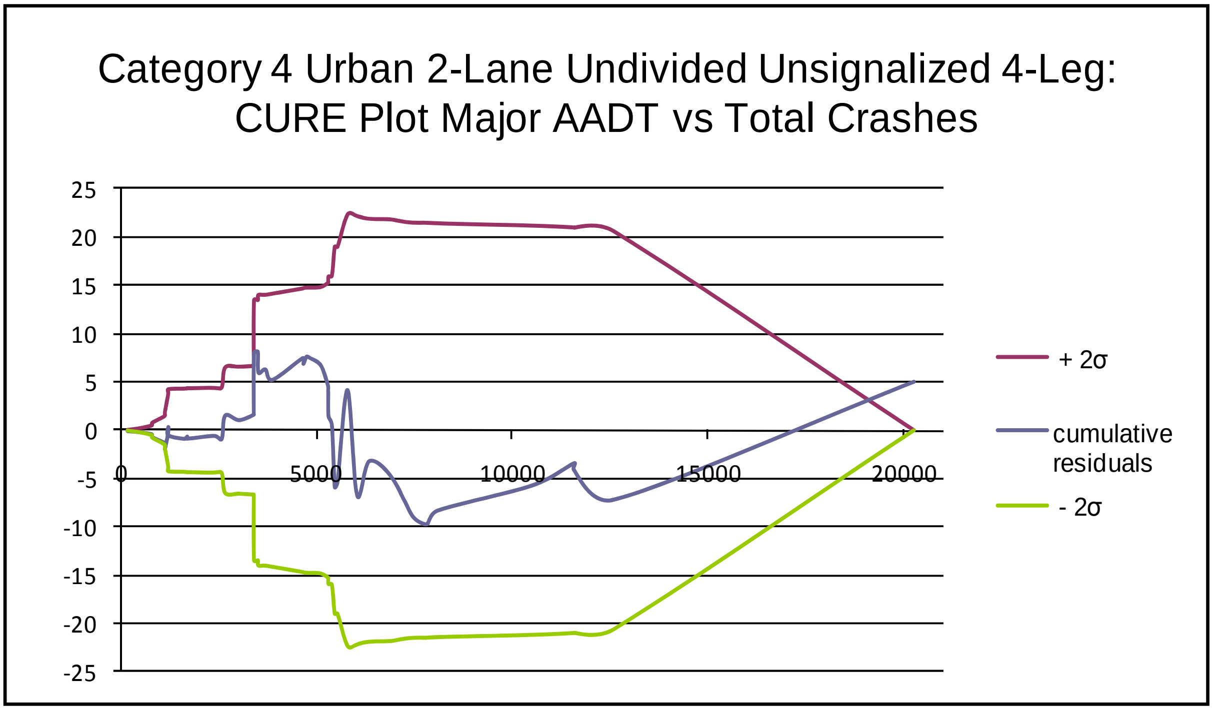

Category 2 Urban 6-Lane Divided Signalized 4-Leg:
CURE Plot Minor AADT vs Fatal+Injury Crashes
100
80
60
40
20
0
-20
-40
-60
-80
-100
0
10000
20000
30000
40000
50000
+ 2σ
cumulative residuals
- 2σ

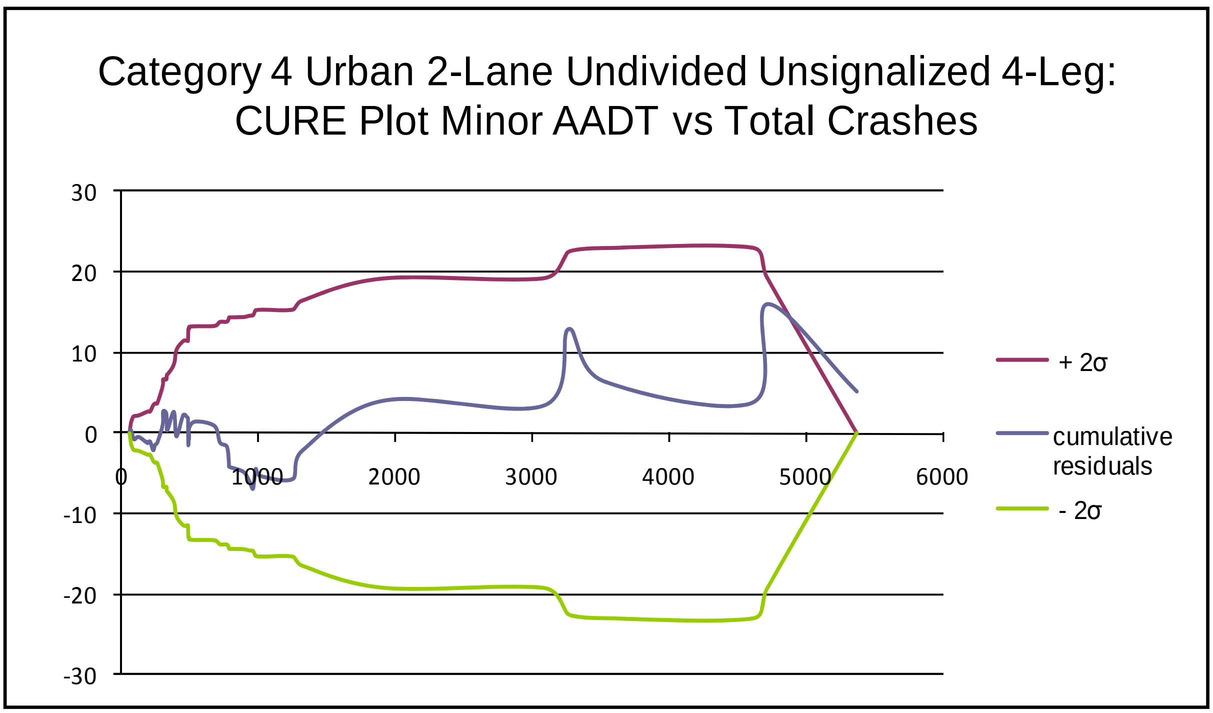

Category 3 Urban 4-Lane Divided Signalized 3-Leg:
CURE Plot Major AADT vs Total Crashes
200
150
100
50
0
-50
-100
-150
-200
0
10000
20000
30000
40000
50000
60000
70000
+ 2σ
cumulative residuals
- 2σ

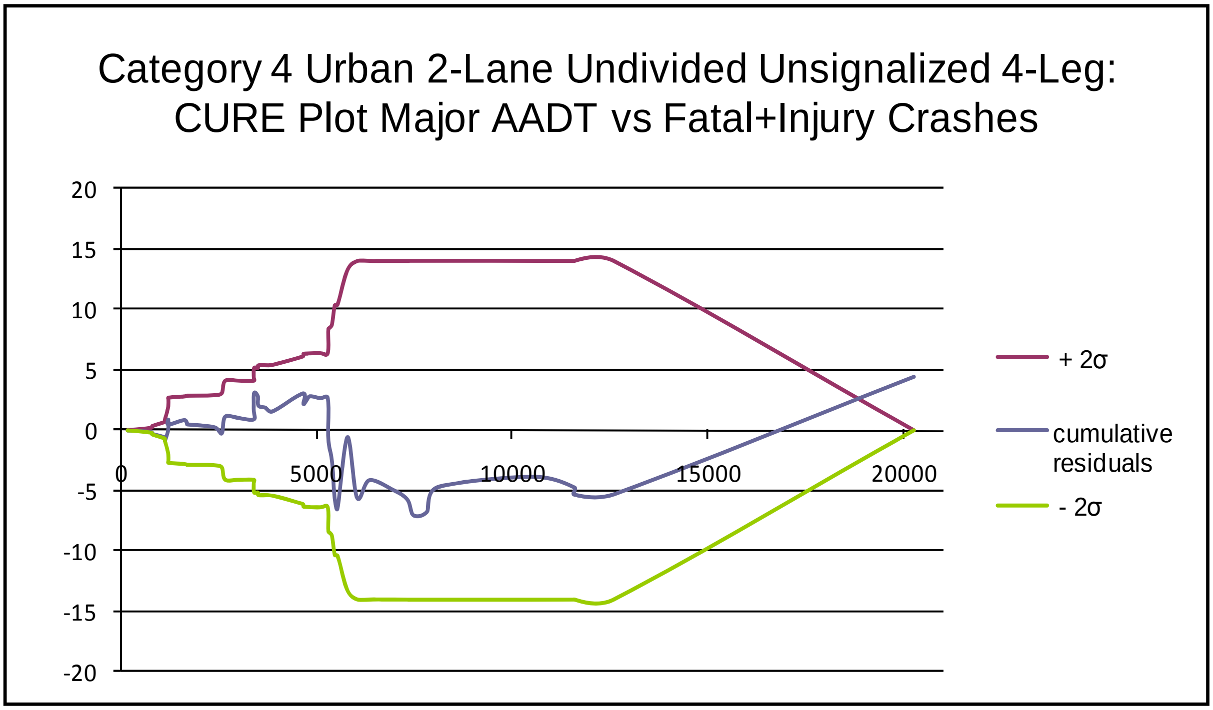

Category 3 Urban 4-Lane Divided Signalized 3-Leg:
CURE Plot Minor AADT vs Total Crashes
200
150
100
50
0
-50
-100
-150
-200
0
5000
10000
15000
20000
+ 2σ
cumulative residuals
- 2σ

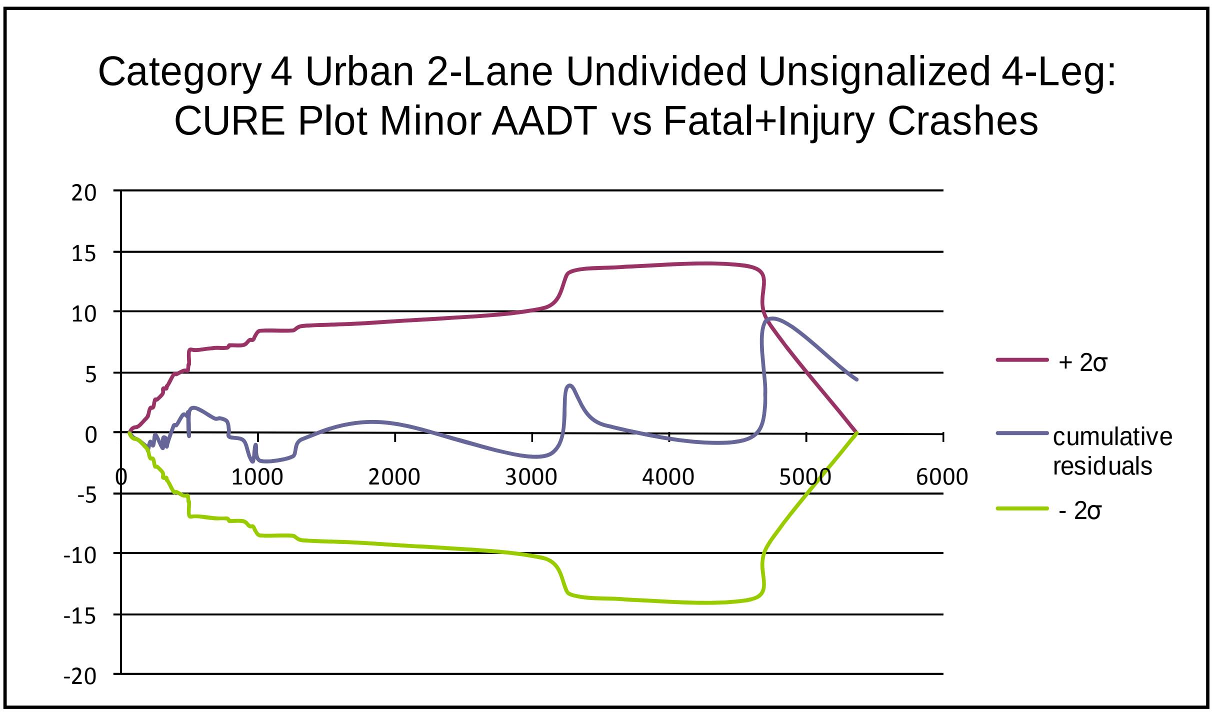

Category 3 Urban 4-Lane Divided Signalized 3-Leg:
CURE Plot Major AADT vs Fatal+Injury Crashes
60
40
20
0
-20
-40
-60
0
10000
20000
30000
40000
50000
60000
70000
+ 2σ
cumulative residuals
- 2σ

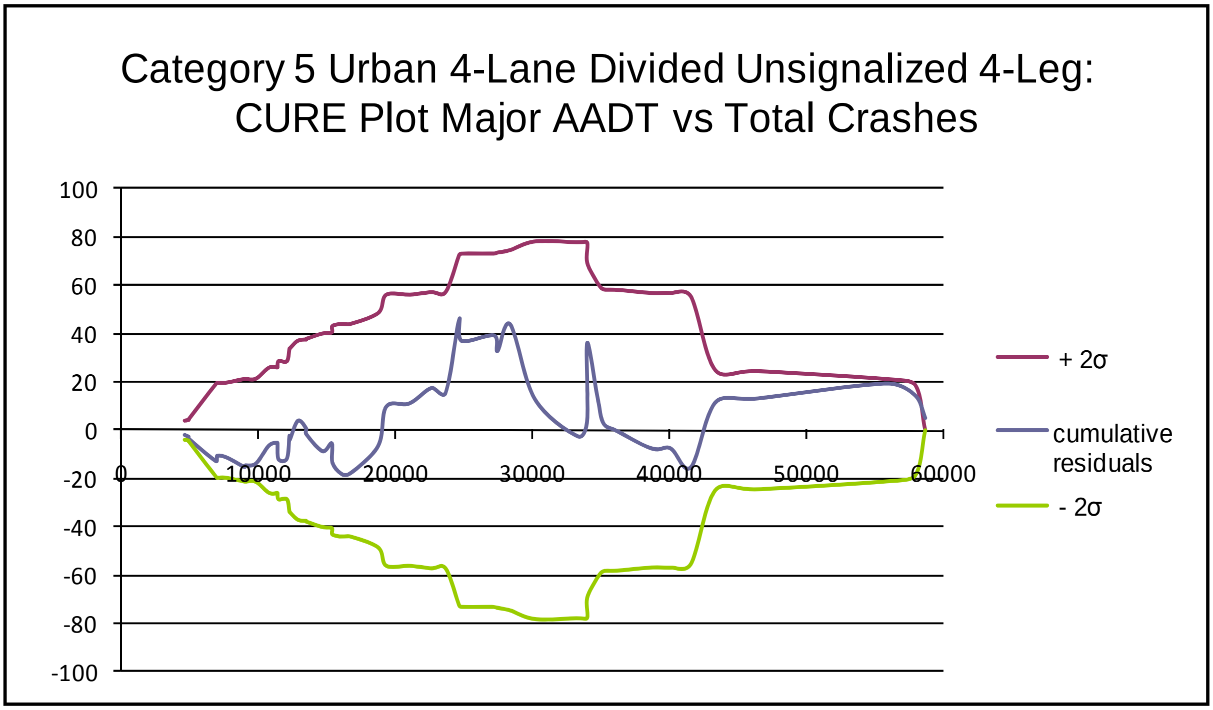

Category 3 Urban 4-Lane Divided Signalized 3-Leg:
CURE Plot Minor AADT vs Fatal+Injury Crashes
60
40
20
0
-20
-40
-60
0
5000
10000
15000
20000
+ 2σ
cumulative residuals
- 2σ

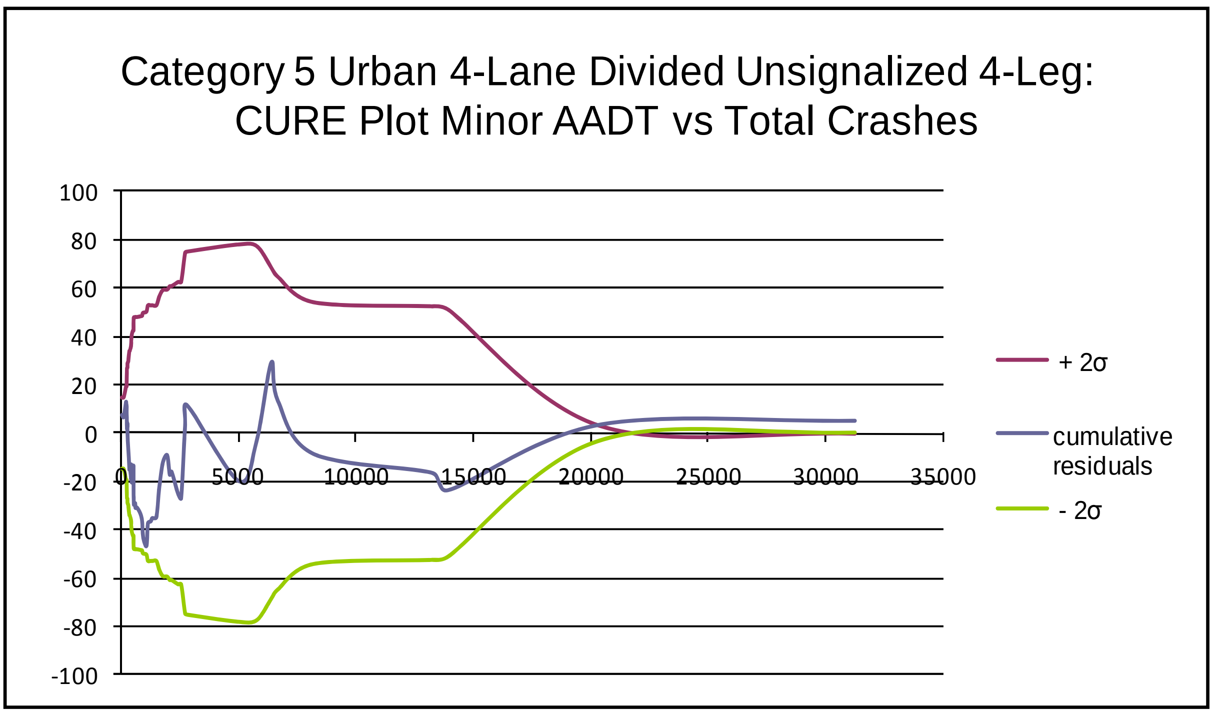

Category 4 Urban 2-Lane Undivided Unsignalized 4-Leg:
CURE Plot Major AADT vs Total Crashes
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
5000
10000
15000
20000
+ 2σ
cumulative residuals
- 2σ

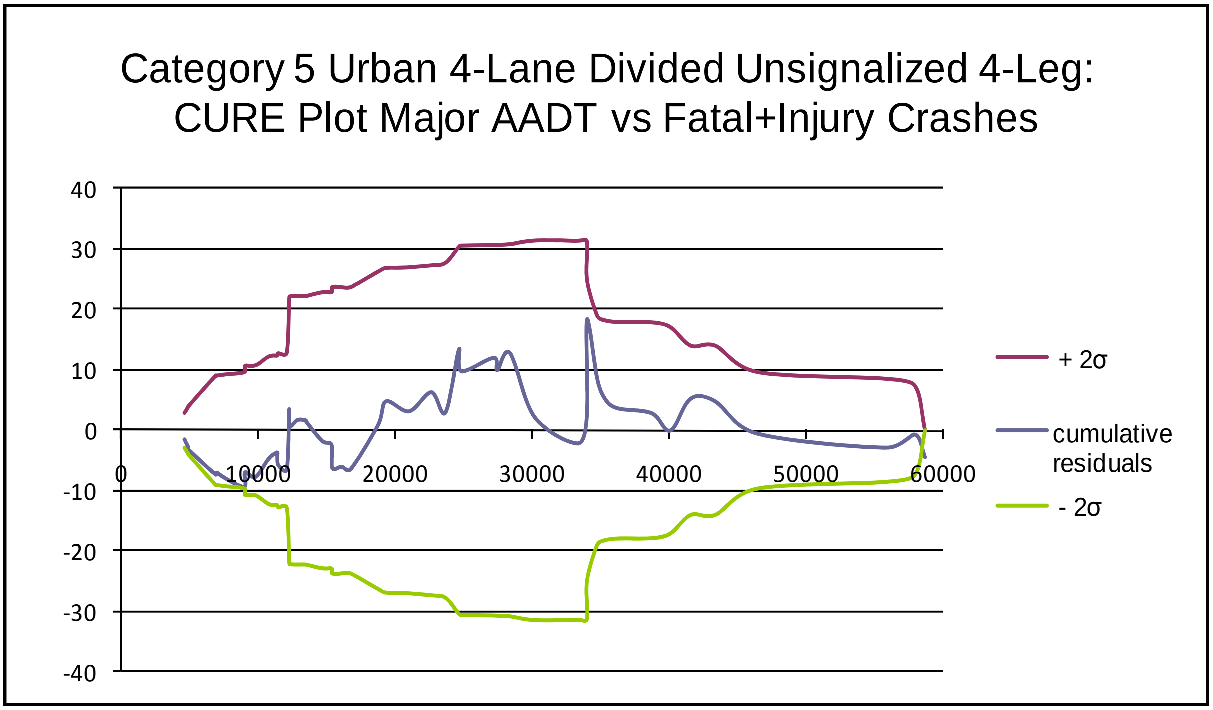

Category 4 Urban 2-Lane Undivided Unsignalized 4-Leg:
CURE Plot Minor AADT vs Total Crashes
30
20
10
0
-10
-20
-30
0
1000
2000
3000
4000
5000
6000
+ 2σ
cumulative residuals
- 2σ

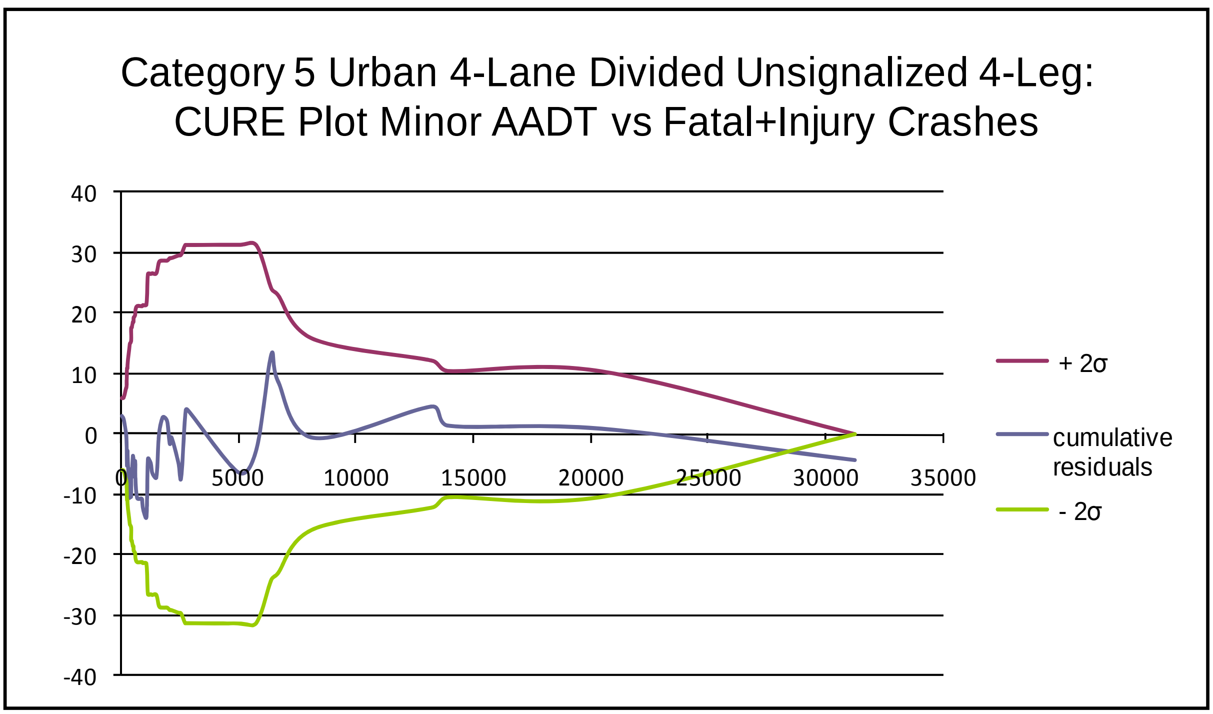

Category 4 Urban 2-Lane Undivided Unsignalized 4-Leg:
CURE Plot Major AADT vs Fatal+Injury Crashes
20
15
10
5
0
-5
-10
-15
-20
0
5000
10000
15000
20000
+ 2σ
cumulative residuals
- 2σ

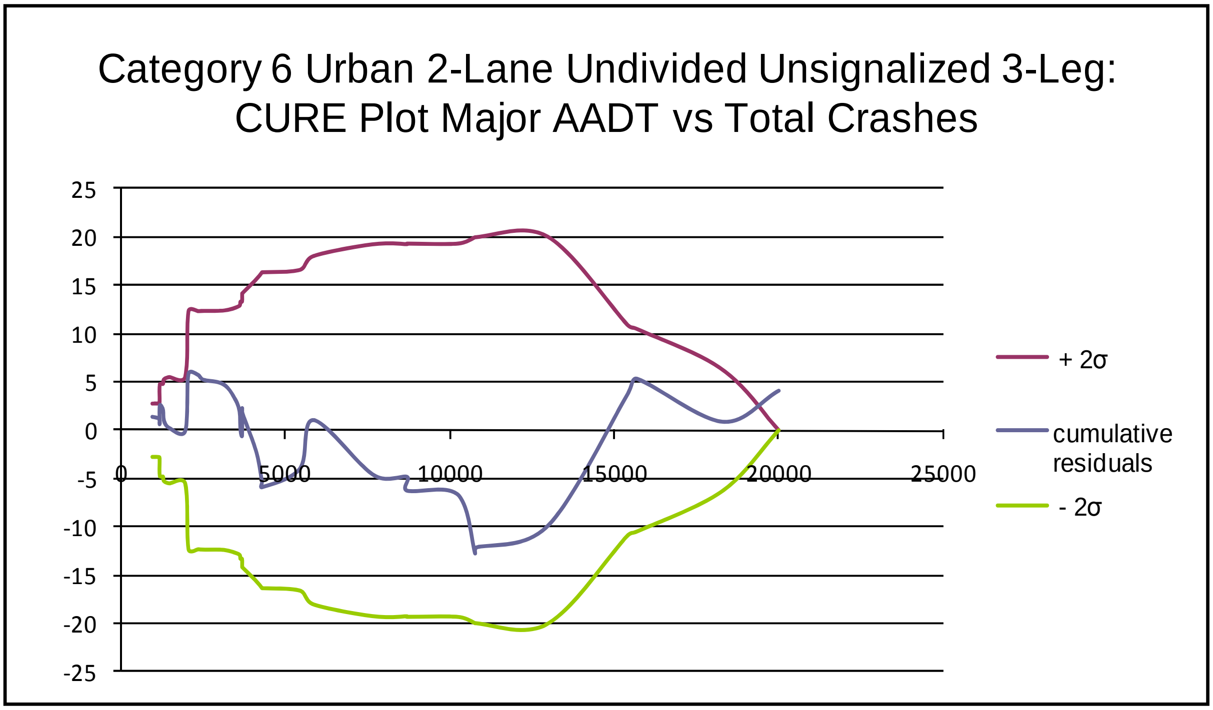

Category 4 Urban 2-Lane Undivided Unsignalized 4-Leg:
CURE Plot Minor AADT vs Fatal+Injury Crashes
20
15
10
5
0
-5
-10
-15
-20
0
1000
2000
3000
4000
5000
6000
+ 2σ
cumulative residuals
- 2σ

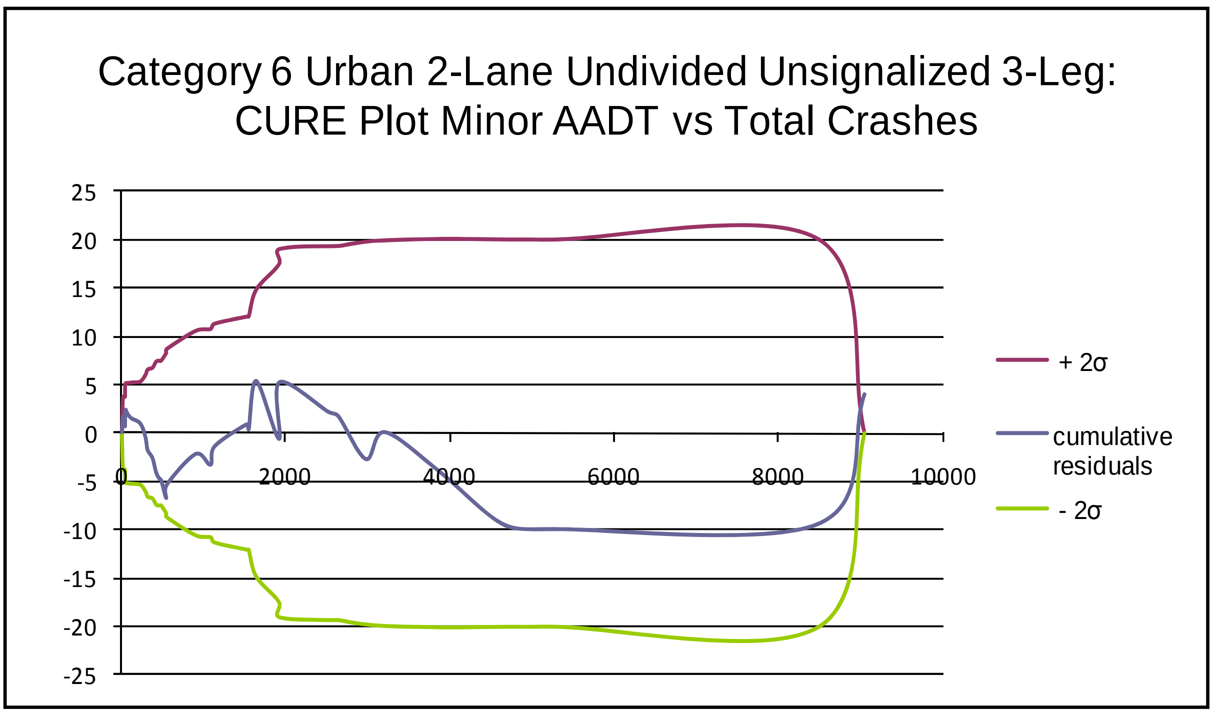

Category 5 Urban 4-Lane Divided Unsignalized 4-Leg:
CURE Plot Major AADT vs Total Crashes
100
80
60
40
20
0
-20
-40
-60
-80
-100
0
10000
20000
30000
40000
50000
60000
+ 2σ
cumulative residuals
- 2σ

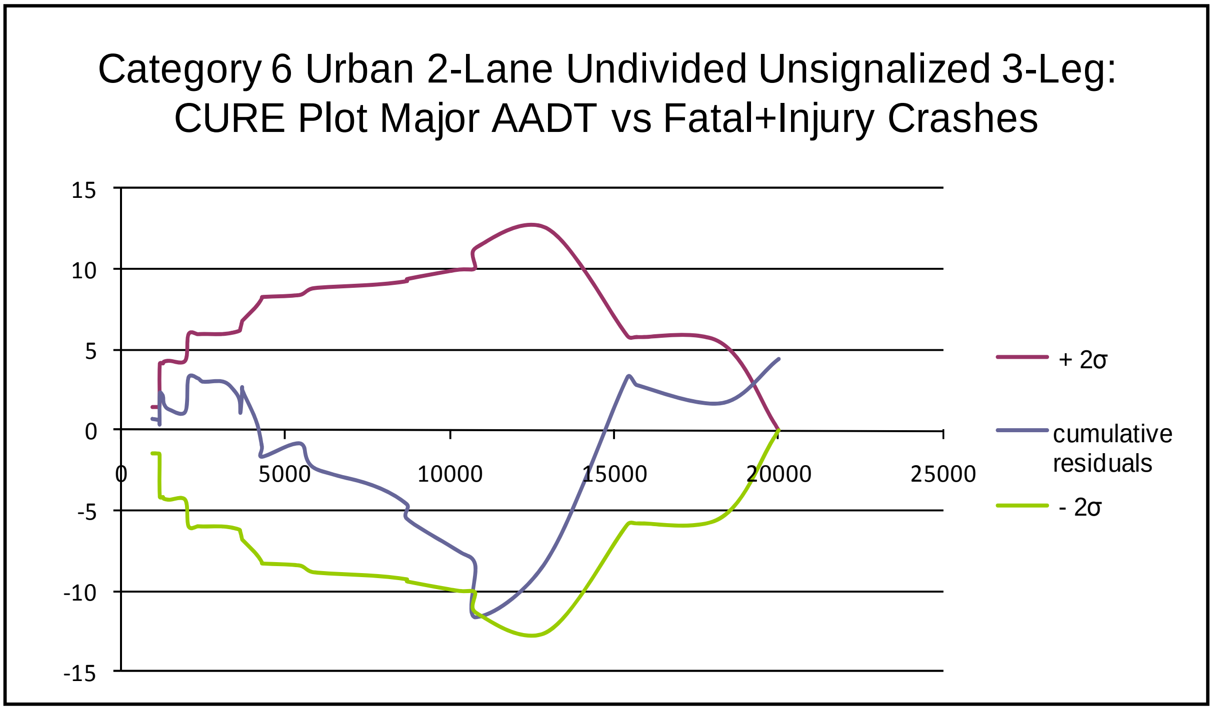

Category 5 Urban 4-Lane Divided Unsignalized 4-Leg:
CURE Plot Minor AADT vs Total Crashes
100
80
60
40
20
0
-20
-40
-60
-80
-100
0
5000
10000
15000
20000
25000
30000
35000
+ 2σ
cumulative residuals
- 2σ

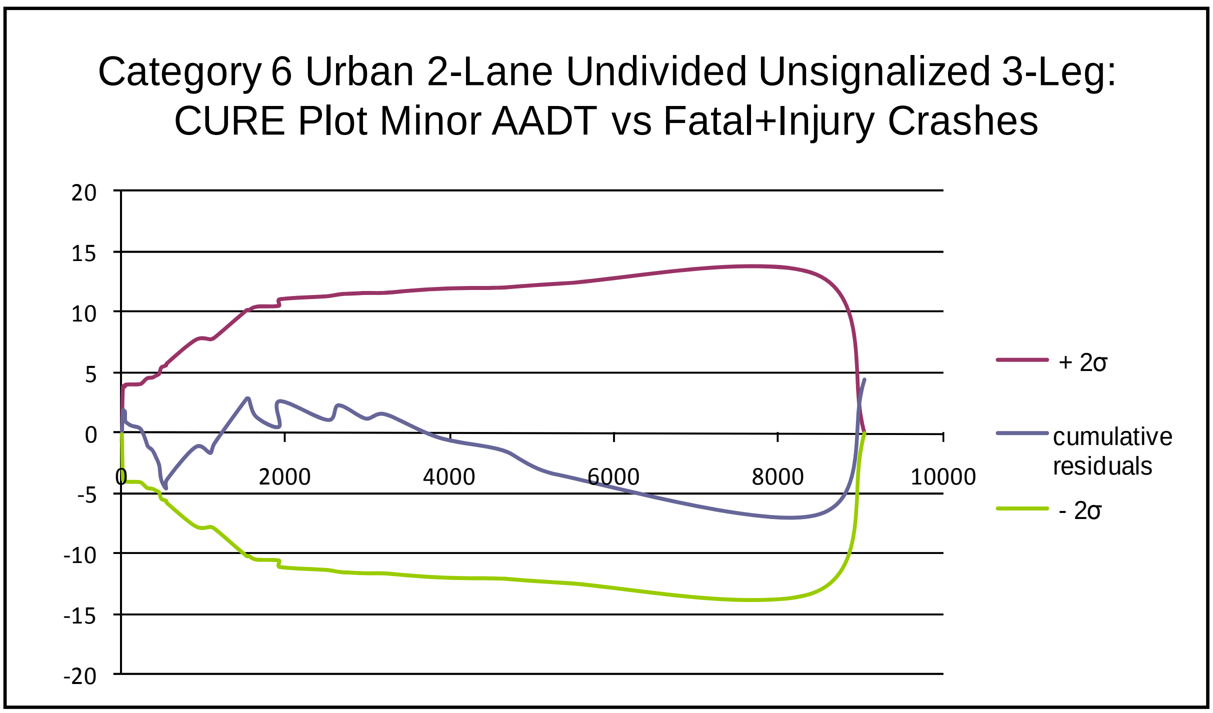

Category 5 Urban 4-Lane Divided Unsignalized 4-Leg:
CURE Plot Major AADT vs Fatal+Injury Crashes
40
30
20
10
0
-10
-20
-30
-40
0
10000
20000
30000
40000
50000
60000
+ 2σ
cumulative residuals
- 2σ


Category 5 Urban 4-Lane Divided Unsignalized 4-Leg:
CURE Plot Minor AADT vs Fatal+Injury Crashes
40
30
20
10
0
-10
-20
-30
-40
0
5000
10000
15000
20000
25000
30000
35000
+ 2σ
cumulative residuals
- 2σ

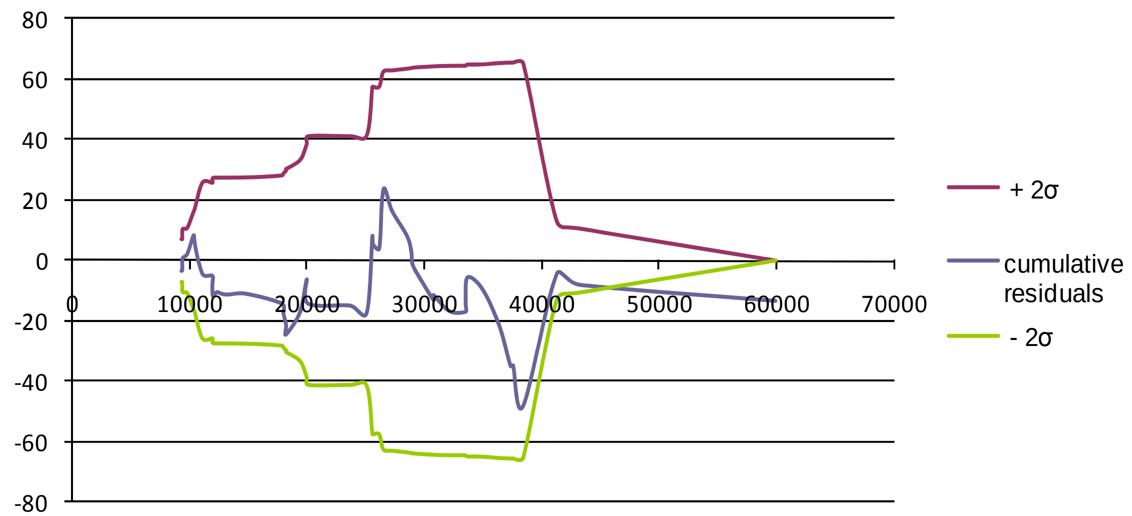

Category 6 Urban 2-Lane Undivided Unsignalized 3-Leg:
CURE Plot Major AADT vs Total Crashes
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
5000
10000
15000
20000
25000
+ 2σ
cumulative residuals
- 2σ


Category 6 Urban 2-Lane Undivided Unsignalized 3-Leg:
CURE Plot Minor AADT vs Total Crashes
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
2000
4000
6000
8000
10000
+ 2σ
cumulative residuals
- 2σ

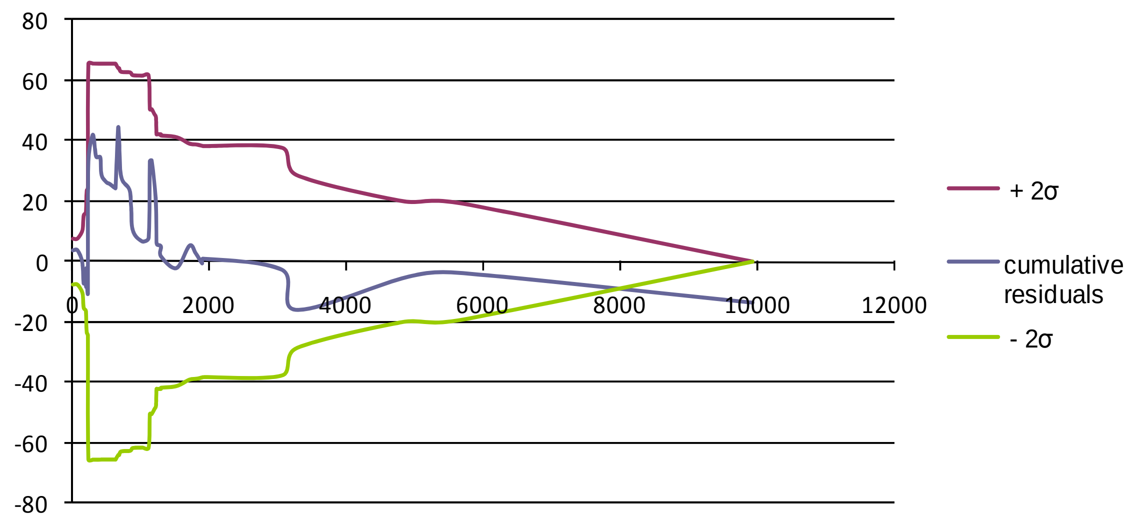

Category 6 Urban 2-Lane Undivided Unsignalized 3-Leg:
CURE Plot Major AADT vs Fatal+Injury Crashes
15
10
5
0
-5
-10
-15
0
5000
10000
15000
20000
25000
+ 2σ
cumulative residuals
- 2σ

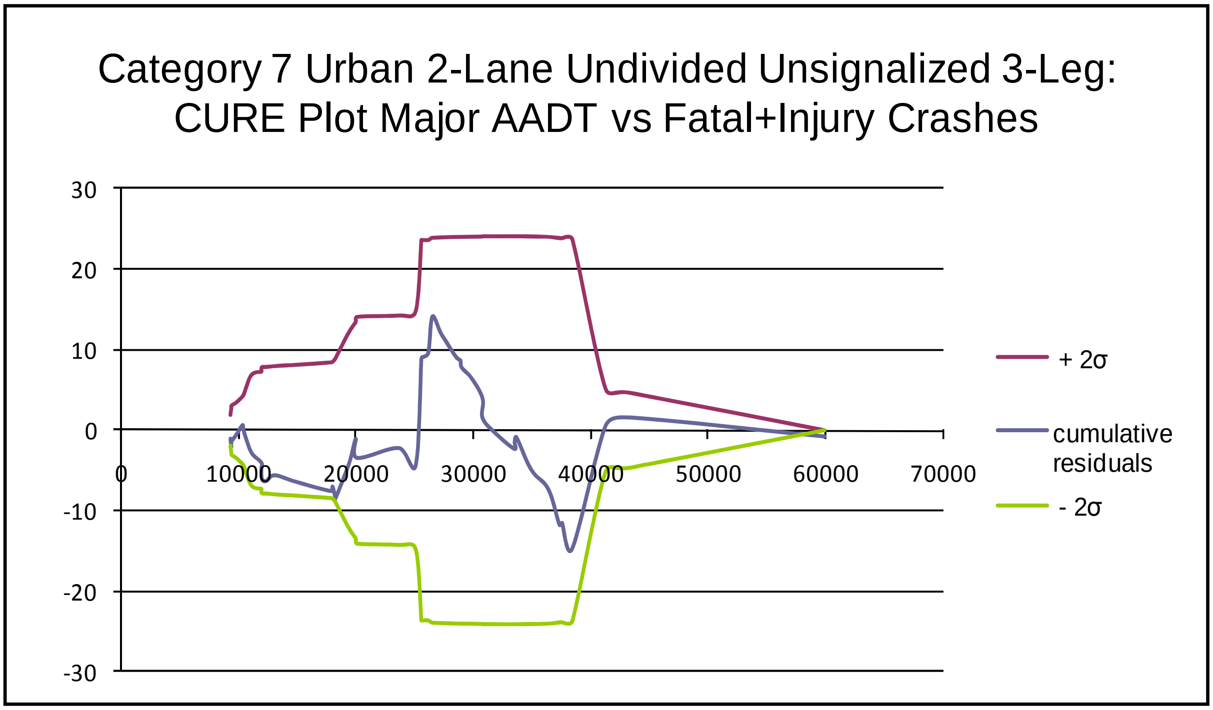

Category 6 Urban 2-Lane Undivided Unsignalized 3-Leg:
CURE Plot Minor AADT vs Fatal+Injury Crashes
20
15
10
5
0
-5
-10
-15
-20
0
2000
4000
6000
8000
10000
+ 2σ
cumulative residuals
- 2σ

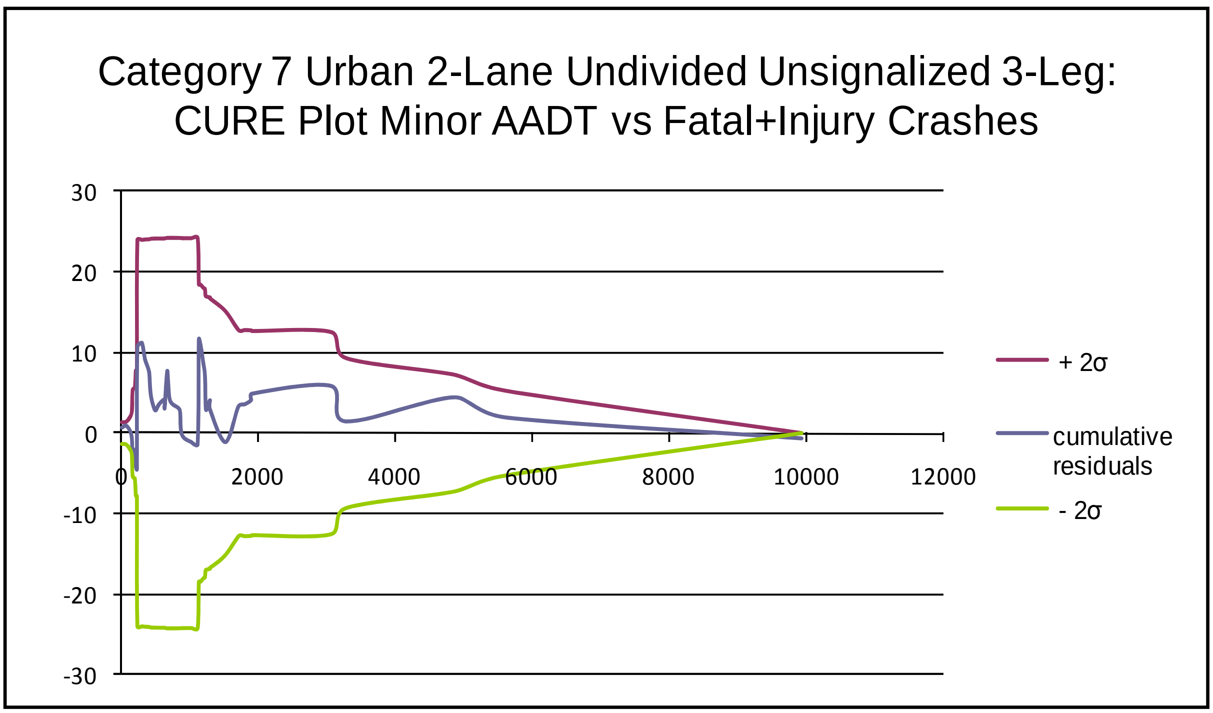
Category 7 Urban 2-Lane Undivided Unsignalized 3-Leg: CURE Plot Major AADT vs Total Crashes



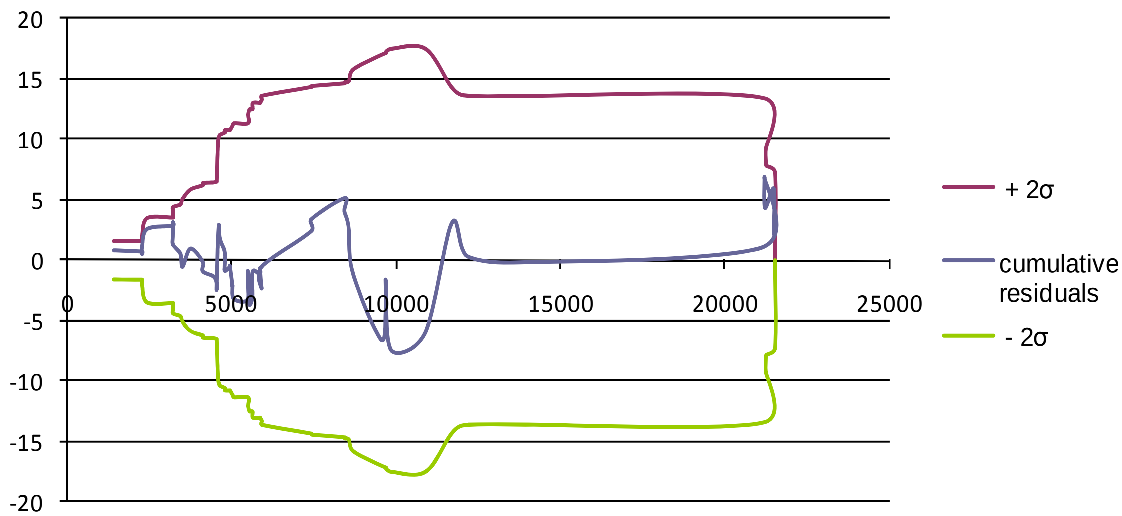
Category 7 Urban 2-Lane Undivided Unsignalized 3-Leg: CURE Plot Minor AADT vs Total Crashes



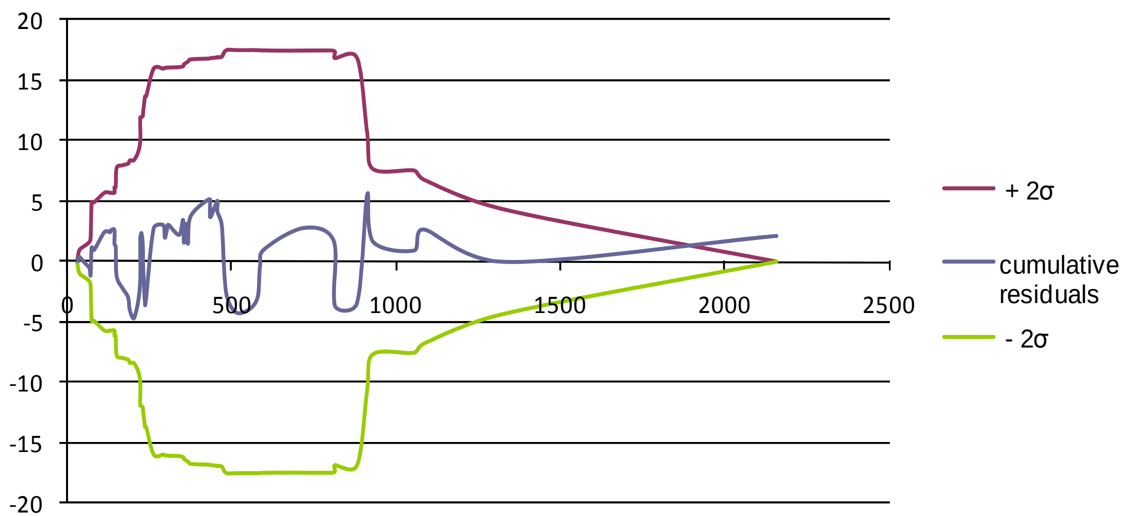

Category 7 Urban 2-Lane Undivided Unsignalized 3-Leg:
CURE Plot Major AADT vs Fatal+Injury Crashes
30
20
10
0
-10
-20
-30
0
10000
20000
30000
40000
50000
60000
70000
+ 2σ
cumulative residuals
- 2σ

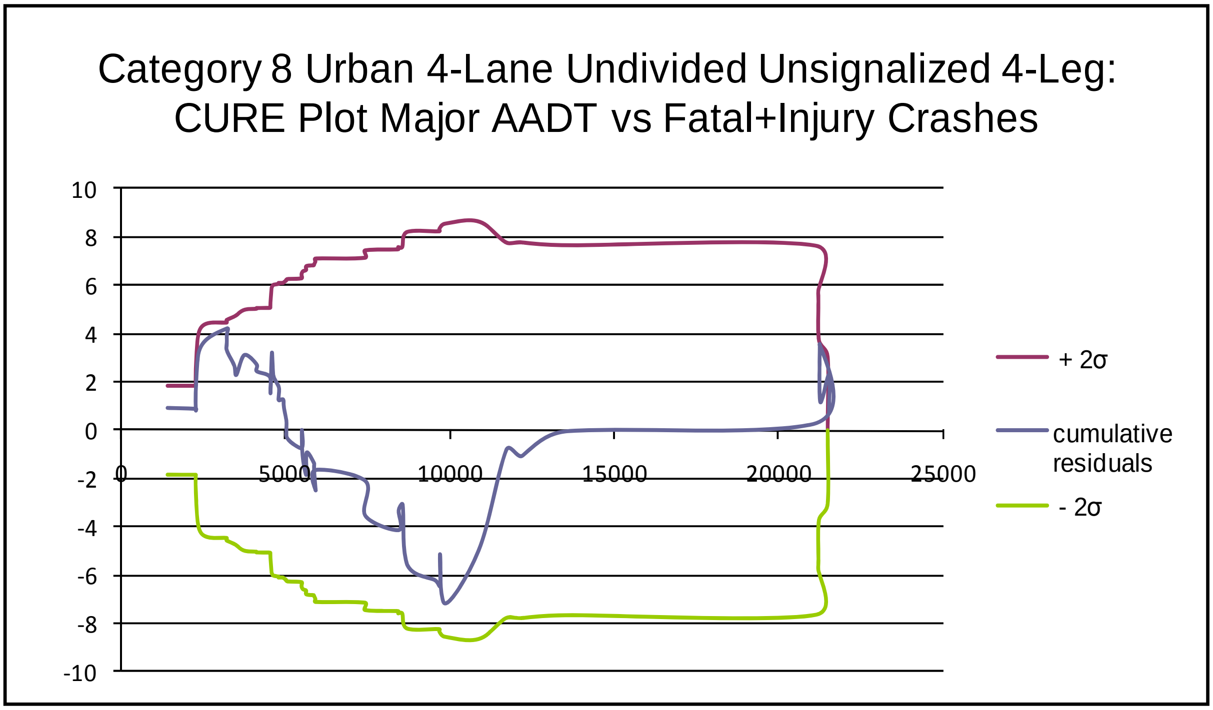

Category 7 Urban 2-Lane Undivided Unsignalized 3-Leg:
CURE Plot Minor AADT vs Fatal+Injury Crashes
30
20
10
0
-10
-20
-30
0
2000
4000
6000
8000
10000
12000
+ 2σ
cumulative residuals
- 2σ

Category 8 Urban 4-Lane Undivided Unsignalized 4-Leg: CURE Plot Major AADT vs Total Crashes

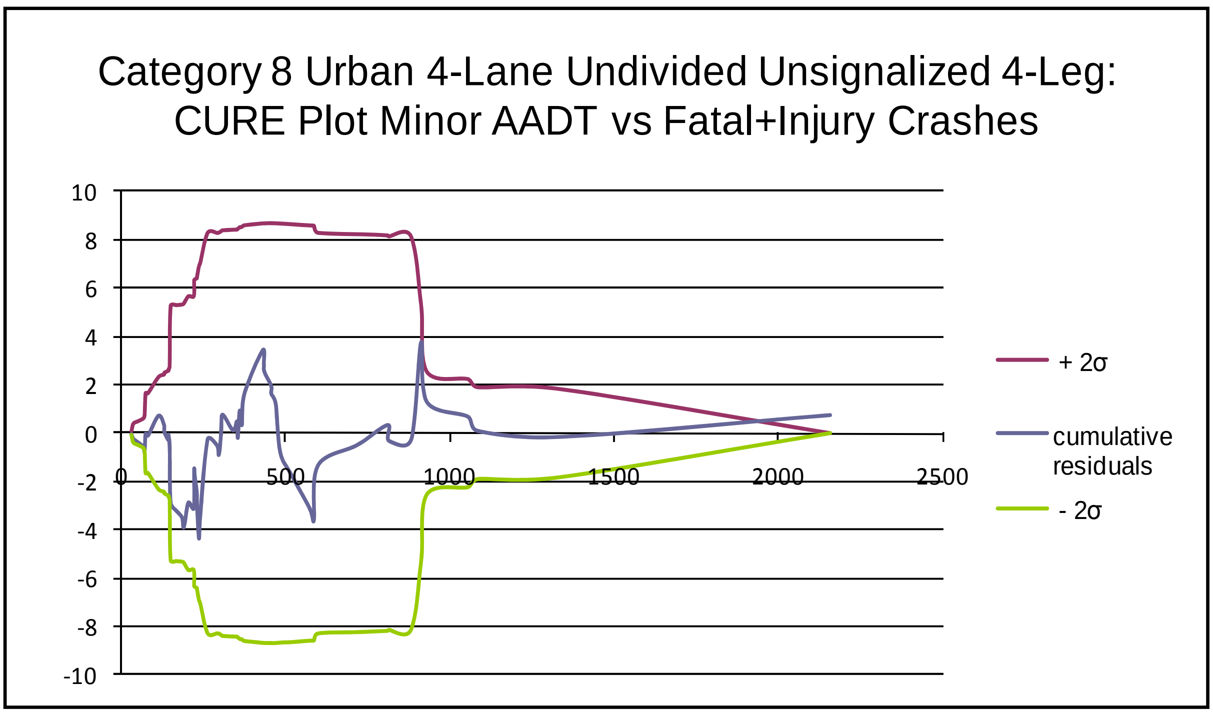


Category 8 Urban 4-Lane Undivided Unsignalized 4-Leg: CURE Plot Minor AADT vs Total Crashes

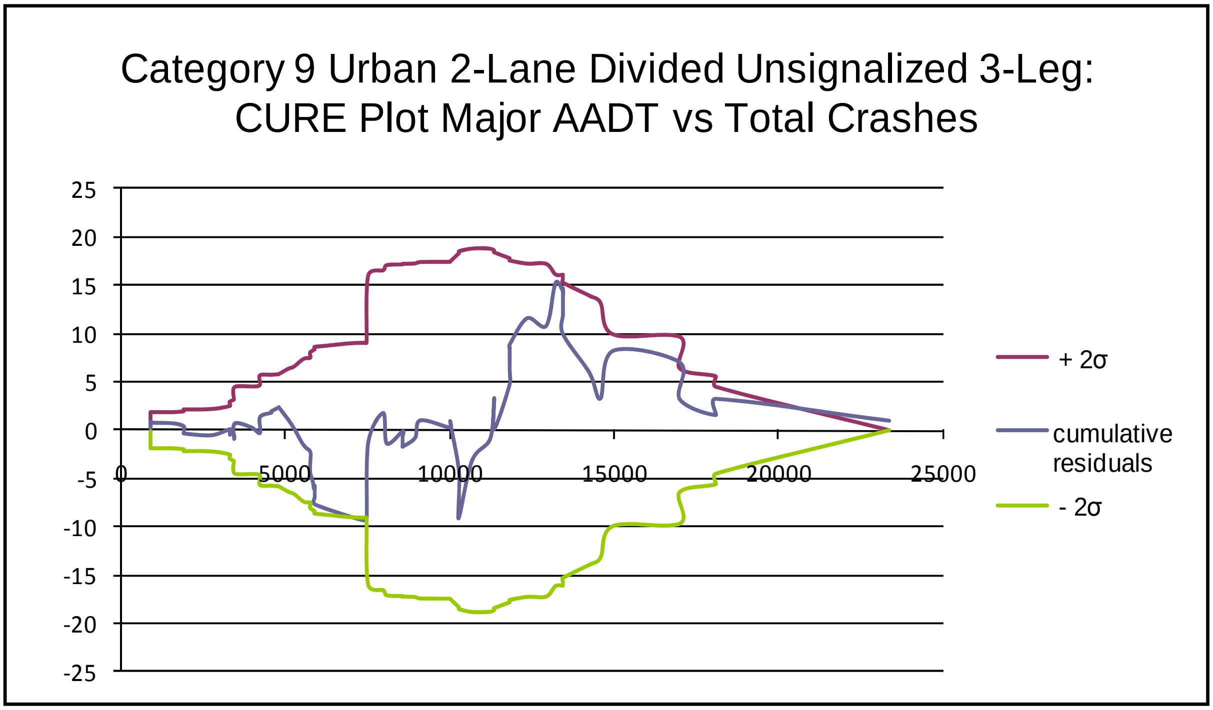




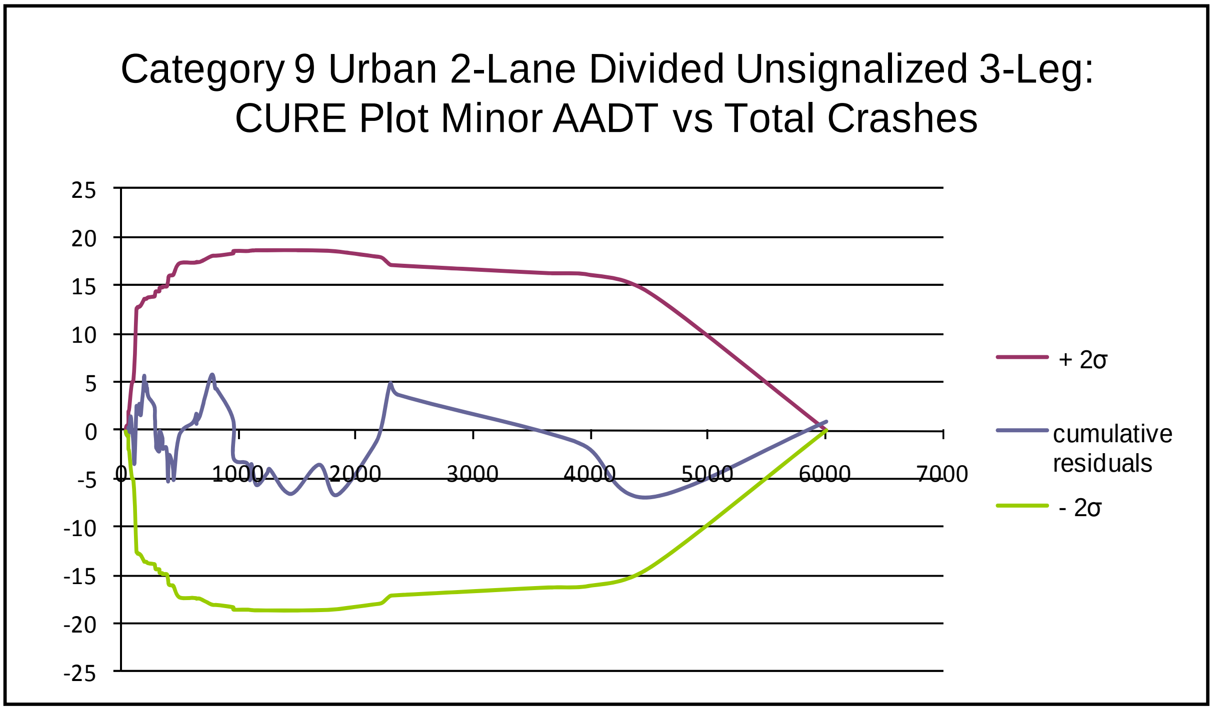
Category 8 Urban 4-Lane Undivided Unsignalized 4-Leg:
CURE Plot Major AADT vs Fatal+Injury Crashes
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
5000
10000
15000
20000
25000
+ 2σ
cumulative residuals
- 2σ



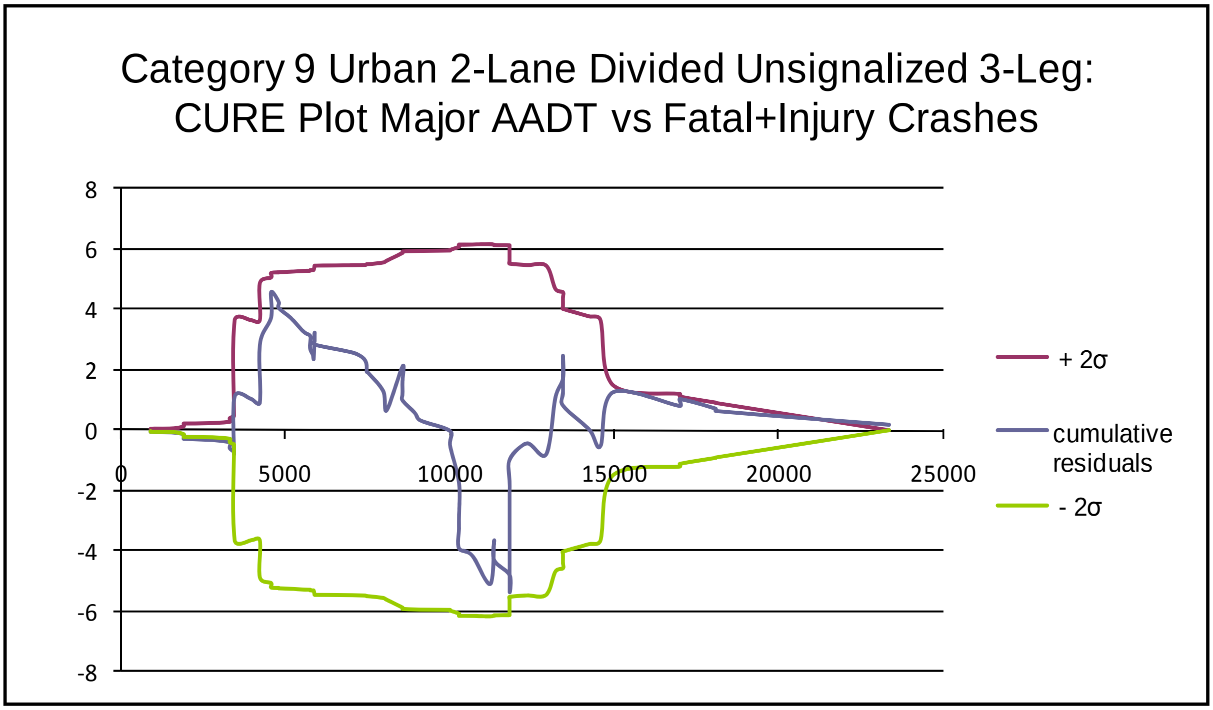
Category 8 Urban 4-Lane Undivided Unsignalized 4-Leg:
CURE Plot Minor AADT vs Fatal+Injury Crashes
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
500
1000
1500
2000
2500
+ 2σ
cumulative residuals
- 2σ

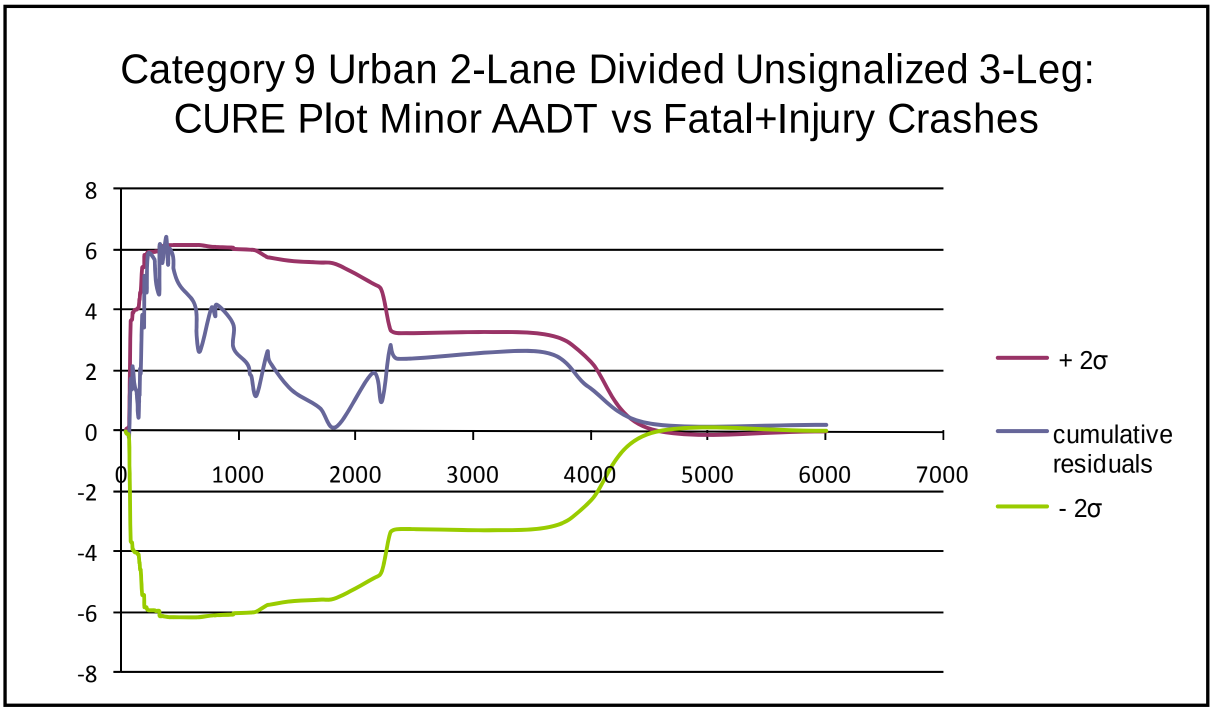


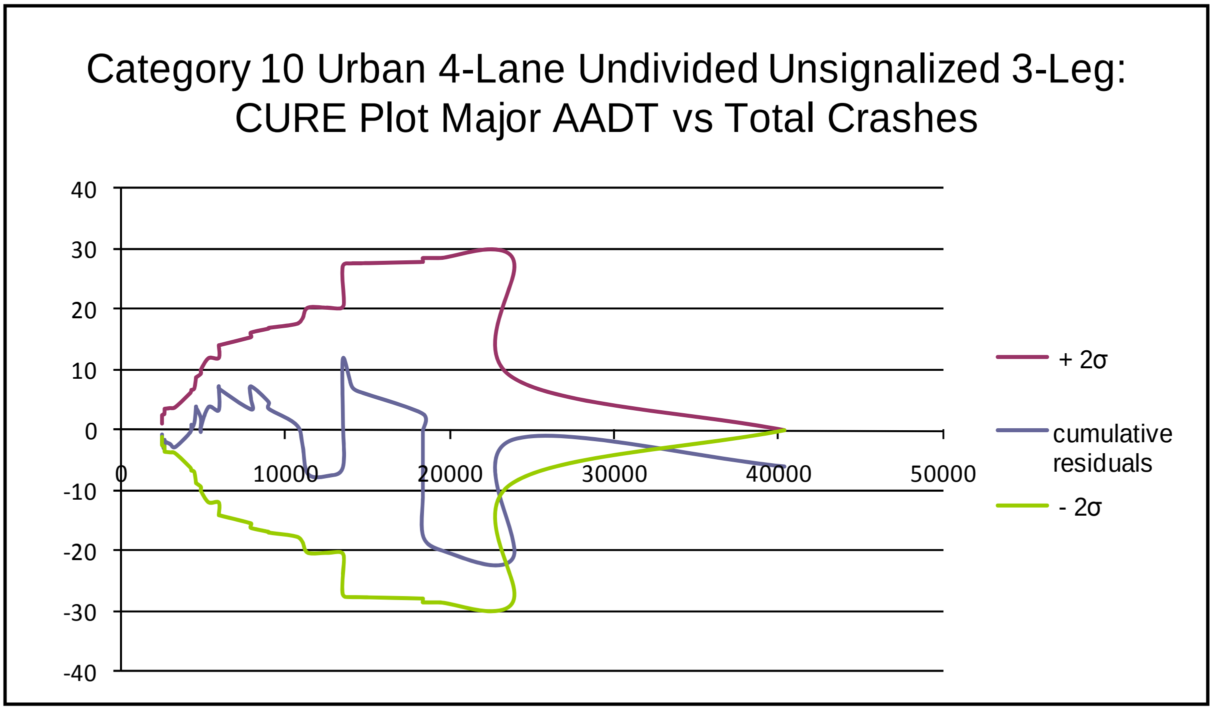
Category 9 Urban 2-Lane Divided Unsignalized 3-Leg:
CURE Plot Major AADT vs Total Crashes
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
5000
10000
15000
20000
25000
+ 2σ
cumulative residuals
- 2σ

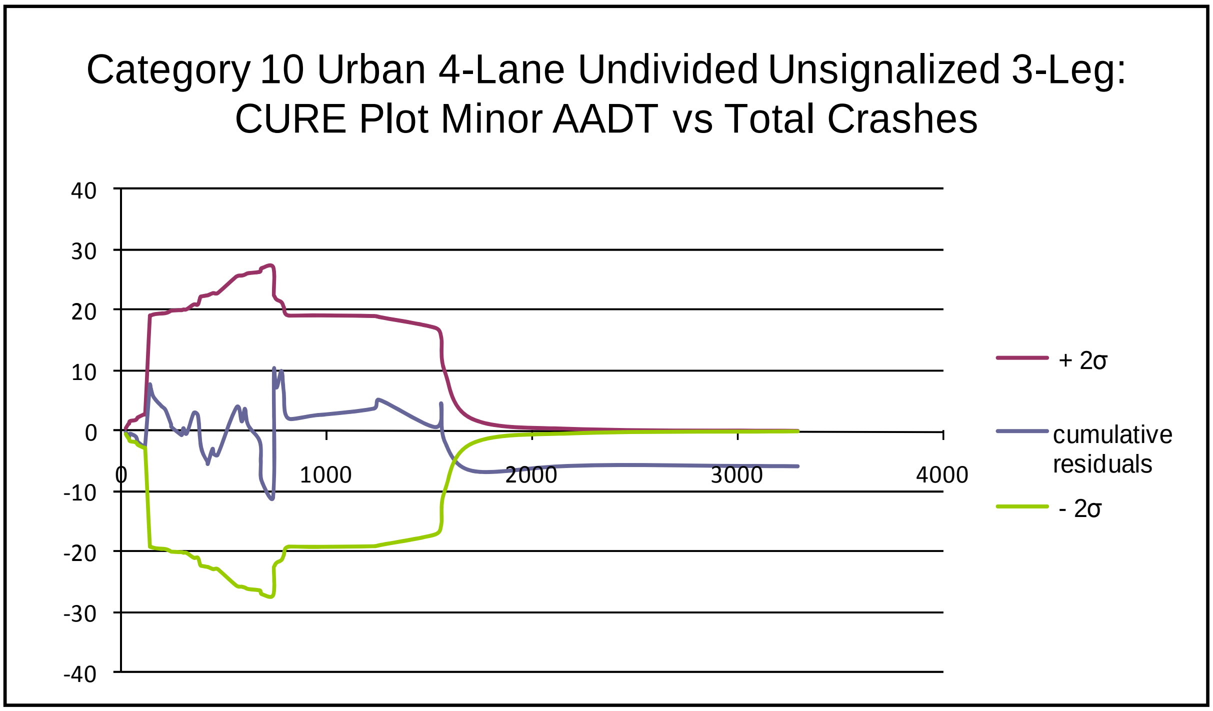


Category 9 Urban 2-Lane Divided Unsignalized 3-Leg:
CURE Plot Minor AADT vs Total Crashes
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
1000
2000
3000
4000
5000
6000
7000
+ 2σ
cumulative residuals
- 2σ


Category 9 Urban 2-Lane Divided Unsignalized 3-Leg:
CURE Plot Major AADT vs Fatal+Injury Crashes
8
6
4
2
0
-2
-4
-6
-8
0
5000
10000
15000
20000
25000
+ 2σ
cumulative residuals
- 2σ


Category 9 Urban 2-Lane Divided Unsignalized 3-Leg:
CURE Plot Minor AADT vs Fatal+Injury Crashes
8
6
4
2
0
-2
-4
-6
-8
0
1000
2000
3000
4000
5000
6000
7000
+ 2σ
cumulative residuals
- 2σ


Category 10 Urban 4-Lane Undivided Unsignalized 3-Leg:
CURE Plot Major AADT vs Total Crashes
40
30
20
10
0
-10
-20
-30
-40
0
10000
20000
30000
40000
50000
+ 2σ
cumulative residuals
- 2σ


Category 10 Urban 4-Lane Undivided Unsignalized 3-Leg:
CURE Plot Minor AADT vs Total Crashes
40
30
20
10
0
-10
-20
-30
-40
0
1000
2000
3000
4000
+ 2σ
cumulative residuals
- 2σ