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POTENTIAL EFFECTIVENESS OF SIGNAL OPTIMIZATION FOR VARIOUS CORRIDORS IN MICHIGAN

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Potential Effectiveness of Signal Optimization for Various Corridors in Michigan

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16. Abstract

This study investigates the potential effectiveness of signal timing at 130 intersections located on five corridors in southeast Michigan. Effectiveness is measured in terms of reduced numbers of crashes after signal timing was introduced. Five years of Michigan crash data from 2001 through 2005 were used to count crashes both before and after signal timing. For each of the 130 intersections, crash sites were geographically located on maps using a spatial analysis software tool and summary crash statistics were provided for injury severity, time of day, day of week, and crash type. In total, there were 12,438 crashes on the 130 intersections. Approximately 80 percent of these crashes resulted in property damage only, and about half were rear-end type crashes.

A before-after statistical model was developed to assess the effects of signal timing on the numbers of crashes after the intervention. Results are provided for each intersection. Overall, the corridors are ranked in the following order, based on greatest reductions in numbers of crashes after signal timing: Jefferson Avenue, Plymouth Road, Woodward Avenue, Ford Road, and Hall Road. Jefferson Avenue, Plymouth Road, and Woodward Avenue showed overall reductions in crashes after signal timing. Ford Road showed no change, and Hall Road showed an increase in crashes after the treatment. It was hypothesized that the increase in crashes on Hall Road might be due to increased traffic volumes on that corridor due to community and economic development after the signal timing started. Examination of available average daily traffic (ADT) counts before and after treatment did not support that hypothesis.

Crash type and crash severity were investigated to determine if any shifts occurred in these distributions after signal timing. It was found that intersections that showed a significant reduction in numbers of crashes after signal timing had higher percentages of angle crashes and lower percentages of same-direction crashes than intersections that showed no change in crashes after signal timing.

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Potential Effectiveness of Signal Optimization for Various Corridors in Michigan

1. Introduction

This study is an investigation into the potential effectiveness of a signal timing intervention conducted along various corridors in southeast Michigan. Effectiveness is measured in terms of the estimated reductions in the numbers of crashes at signalized intersections attributable to the intervention. The investigation proceeds from the perspective of a before and after study to determine if the numbers of crashes were reduced at specific intersections located along various corridors. In total, 130 intersections were evaluated along five corridors in southeast Michigan. The corridors include Ford Road (M-153, 26 intersections), Plymouth Road (Old M-14, 18 intersections), Jefferson Avenue (10 intersections), Hall Road (M-59, 28 intersections), and Woodward Avenue (M-1, 48 intersections). The intersections on the five corridors are located within two counties in Michigan. The intersections on Ford Road, Plymouth Road, Jefferson Avenue, and Woodward Avenue are located in Wayne County. The intersections on Hall Road are located in Macomb County.

A vast amount of literature exists regarding the design and implementation of before and after studies as they relate to installation or removal of traffic signals. In the National Cooperative Highway Research Program (NCHRP) Research Results Digest 299 [1], a summary of crash reduction factors (CRFs) are provided for a variety of safety treatments. Crash reduction factors are used to estimate the reduction in crashes that can be expected for a specific treatment or installation. The digest makes reference to various impediments that should be addressed when conducting before and after studies:

1. Sample sizes that are too small – Since crashes are rare events, much time may elapse before enough crashes are observed to make a valid inference. This is particularly true at intersections that are less traveled.
2. Change in crash type – Signal timing intervention could lead to a change in the distribution of crash type. For example, one effect might be a shift from low-speed collisions due to congestion, to more high-speed collisions because traffic is flowing more freely after signal timing. In other words, a possible shift from rear-end collisions to right-angle collisions.
3. Crash migration to other intersections – After countermeasures have been implemented, crashes may migrate to adjacent locations. For example, removal of a left turn signal may encourage drivers to make left turns at the next available intersection.

NCHRP Report 491 [2] describes a process for estimating the safety impacts of installing or removing traffic signals and recommends an improved crash experience warrant for the *Manual* *on Uniform Traffic Control Devices (MUTCD)*. NCHRP Report 491 discusses in detail previous research, data collection, study design, and analysis methodology for evaluating crash experience at signalized intersections. Basics of the empirical Bayes before-after study are outlined and illustrative examples are provided for implementing the procedure.

In a treatment of observational before-after studies, Hauer [3] presents various study designs for assessing the effects of countermeasures used in road safety. The *regression to the mean* effect is described as a potential source of bias in before-after studies. Regression to the mean can occur when intersections are selected for treatment due to high crash rates in the before treatment period. The selection bias inherent in this approach often results in exaggerated estimates in favor of the intervention. Hauer describes and advocates use of the empirical Bayes method for conducting before-after studies. This approach is useful for handling regression to the mean bias, as well as some of the other impediments described above.

In this study, the Bayesian method is adopted to assess the effects of signal timing on the 130 intersections situated on five corridors under investigation. The Bayesian method has advantages over other classical methods for various reasons. First, it aids in the estimation of intersections with small numbers of crashes since it incorporates a regression model that borrows strength from other intersections with more crashes. One model is fit to all 130 intersections, and estimates of signal effectiveness compromise between the data and the model. If an intersection has a large number of crashes, then the data represent a good estimate of the number of crashes. If an intersection has a small number of crashes, then the estimate is *smoothed* towards the model estimate based on all 130 intersections. For a description of the Bayesian method used in this study, along with an example, see Appendix A.

This report is organized in the following manner. Section 2 describes the Michigan crash data that were used to assess the potential effectiveness of the signal timing procedure. Section 3 presents the study methodology in two stages. The first stage addresses issues related to geographically locating crashes on maps before and after signal timing using a spatial analysis software tool. The second stage describes the before-after statistical methods to determine if numbers of crashes were reduced after signal timing. Sections 4 through 8 give the results of the before-after analysis for each of the five corridors separately. The order of the presentation is Ford Road (M-153), Plymouth Road (Old M-14), Jefferson Avenue, Hall Road (M-59), and Woodward Avenue (M-1). Section 9 explores the associations between the signal timing treatment and two outcome variables (crash type and crash severity). The question to be answered is whether signal timing resulted in shifts in the distributions of either of these two variables. Section 10 discusses the impact of any changes in traffic volumes or average daily traffic (ADT) counts during the before and after periods on the five corridors being investigated. Section 11 summarizes results and conclusions.

2. Data

Five years of Michigan crash data from 2001 through 2005 were obtained from the University of Michigan Transportation Research Institute (UMTRI) Data Center. Since this study focuses on data at the crash level, two types of records were extracted from the Michigan crash files. The first record type contains crash-level variables particular to the crash such as injury severity, date of the crash, time of day, and crash type. The second record type contains crash location information such as latitude/longitude coordinates, county of crash, and direction of travel. Records from these two file types were combined in order to build the database used in this study.

Combining Michigan data over five years was facilitated by the fact that Michigan uses a standardized format for recording data. Since the coding of variables has been consistent over the years, recoding or transforming variables was not necessary when combining data collected from different years. The data values follow the format outlined by the State of Michigan Traffic Crash Report form (UD-10) closely. The UD-10 is prescribed by the Director of the Department of State Police and is a two-sided form designed to capture information about a crash that involved a motor vehicle that was in transport on a roadway and that resulted in death, injury, or property damage of $1,000 or more (effective January 1, 2004) [4]. Forms are completed by investigating officers and submitted by law enforcement agencies for processing to the Criminal Justice Information Center of the Michigan Department of State Police.

After restricting the data to crashes that occurred in Wayne and Macomb counties between 2001 and 2005, the original database used in this study contained 104 variables and records for 488,149 crashes.

3. Methods

Methods for analysis of the data were carried out in two stages. The first stage was devoted to geographically locating crashes at intersections before and after the signal timing intervention. The second stage focused on conducting a before and after study using statistical methods to determine if the numbers of crashes were significantly reduced after the signal timing intervention.

3.1 Geographical Location of Michigan Crash Data

Crashes occurring at the designated intersections between 2001 and 2005 were geographically located using a mapping and spatial analysis software tool [5]. The before and after dates of the signal timings for the 130 intersections were provided by the Michigan Department of Transportation (MDOT) Metro Region Offices. Using the software mapping tool and latitude/longitude coordinates available in the Michigan crash file, crashes were geographically located at each intersection and numbers of crashes were counted both before and after the intervention. Appendix B, provided in a separate volume as a supplement to this report, contains geographical maps for each intersection grouped by corridor[1]. Included on the maps are numbers of crashes before and after signal timing. Descriptive statistics showing distributions of crashes by time of day, day of the week, injury severity, and crash type are also provided.

Since this study focuses on crashes at intersections, the majority of crashes were rear-end or angle type crashes. Other types of crashes such as single-vehicle, head-on, or sideswipe crashes occurred with much less frequency. In addition, the vast majority of crashes were property-damage-only crashes. In total, between 2001 and 2005 there were 12,438 crashes on the 130 intersections under investigation in this study. Table 1 shows the distribution of maximum injury severity in the crash by crash type. Note that 9,856, or 79.2 percent, of the crashes resulted in property damage only. Furthermore, 6,091 of the crashes, or about half, were rear-end type crashes, and 4,860, or 39.1 percent, were rear-end crashes resulting in property damage only. There were 13 fatal involvements, and the total of all K, A, and B injury involvements was 648, or 5.2 percent.

Table 1. Distribution of Injury Severity by Crash Type for 130 Intersections on Five Corridors in Southeast Michigan (Michigan Crash Data, 2001-2005)

	Injury Severity					
Crash Type	K	A	B	C	O	Total
Single-vehicle	6	36	49	77	274	442
Head-on	1	24	67	164	457	713
Angle	4	62	178	427	1,940	2,611
Rear-end	1	40	106	1,084	4,860	6,091
Sideswipe	0	5	17	115	1,819	1,956
Unknown	1	15	36	67	506	625
Total	13	182	453	1,934	9,856	12,438

At most intersections, crashes were counted within a 300 feet radius from the center of the intersection. However, due to geographical characteristics of some of the intersections, a 300 feet radius was not feasible and some of the counts were made within 150 feet or 200 feet (see, for example, the maps for Woodward and Davison or Woodward and Interstate 75 in Appendix B). In addition, due to the close proximity of some intersections on Jefferson Avenue, crashes were counted within a 100 feet distance inside an oblong-shaped figure (see maps of Jefferson Avenue in Appendix B).

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[1] Many of the crashes have latitude/longitude coordinates that were recorded identically, resulting in crash points being overlaid atop one another. However, the maps in Appendix B tend to show where clusters of crashes occurred. In addition, they show the configuration of the intersections such as four-legged intersections, Y-intersections, T-intersections, and so on.

Before geographically locating crashes at intersections, missing data percentages on the latitude and longitude coordinates were checked for Wayne and Macomb counties to ensure that results would not be biased due to missing data. If latitude or longitude values are missing in large percentages for certain years, numbers of actual crashes would be underestimated for those periods, and missing data on these values could compromise the before and after analysis. Years 2001 through 2005 inclusive were checked separately. Table 2 shows percentages of missing data by year for the two counties. Missing data percentages for the five years are relatively low. The largest percentage is 4.8 for Wayne County in 2003. Less than 1 percent of data was missing in 2004 and 2005, and between about 1.5 percent and 3.4 percent was missing in 2001 and 2002.

Some patterns in the numbers of crashes occur over the years. The total numbers of crashes in Macomb County remain fairly constant at about 25,000 to 26,000 per year. However, the total numbers of crashes in Wayne County show a declining trend from 80,735 in 2001 to 63,259 in 2005. In Wayne County, this represents a decrease of about 22 percent over five years. A check of population change by county, according to statistics provided by the U.S. Census Bureau and

Table 2. Missing Data Percentages for Latitude and Longitude Coordinates by Year and County (Michigan Crash Data, 2001-2005)

2001					
County	Recorded	%	Missing	%	Total
Macomb	25,681	98.5	378	1.5	26,059
Wayne	78,721	97.5	2,014	2.5	80,735
Total	104,402	97.8	2,392	2.2	106,794
2002					
County	Recorded	%	Missing	%	Total
Macomb	25,941	97.6	635	2.4	26,576
Wayne	72,817	96.6	2,591	3.4	75,408
Total	98,758	96.8	3,226	3.2	101,984
2003					
County	Recorded	%	Missing	%	Total
Macomb	26,139	99.1	231	0.9	26,370
Wayne	67,989	95.2	3,411	4.8	71,400
Total	94,128	96.3	3,642	3.7	97,770
2004					
County	Recorded	%	Missing	%	Total
Macomb	25,011	99.1	227	0.9	25,238
Wayne	67,702	99.8	119	0.2	67,821
Total	92,713	99.6	346	0.4	93,059
2005					
County	Recorded	%	Missing	%	Total
Macomb	25,259	99.9	24	0.1	25,283
Wayne	63,118	99.8	141	0.2	63,259
Total	88,377	99.8	165	0.2	88,542

the Southeast Michigan Council of Governments [6], shows that the estimated change in population from April 2000 to July 2006 decreased by 3.6 percent in Wayne County, while the estimated change in population during the same period in Macomb County increased by 6.2 percent. Although the Michigan crash data used in this study covers years 2001 through 2005, the two sources of data cover very similar time periods. Macomb County shows a decrease in crashes per population density over time since the numbers of crashes remained fairly constant while the total population increased. Wayne County, however, shows a larger decrease in crashes per population density than Macomb County even though its total population decreased. This is due to the relatively large decrease in the number of crashes of about 22 percent in Wayne County. Note that these estimates are county-wide, and do not necessarily apply to the corridors being investigated in this study. Issues related to analysis of crash rates using average daily traffic (ADT) on the study corridors are addressed in Section 10, although it should be pointed out that estimates of ADT are somewhat crude and should be used as guidelines only.

3.2 Before and After Statistical Analysis

A detailed before and after study was conducted to determine if the numbers of crashes were reduced after the signal timing interventions. A complete description of the statistical method is provided in Appendix A. In summary, a statistical model was developed to assess the effectiveness of the signal timing intervention that takes into account the intersection, the intersection corridor, the numbers of crashes before and after signal timing, and the numbers of days before and after signal timing. A model is fit to all 130 intersections that contains parameters for assessing effects due to the intersections, the intersection corridors, the before and after numbers of crashes, and the before and after numbers of days.

Although the model contains several parameters for adjusting the results, one parameter in particular is used to determine if the numbers of crashes were reduced after signal timing. The model contains one of these parameters for each of the 130 intersections under investigation. The null value for this parameter is 1, meaning that this is the value that one would expect if there were no difference in the numbers of crashes before and after signal timing. If the value of this parameter is significantly less than 1 for an individual intersection, then it is concluded that the number of crashes were reduced after signal timing. Alternatively, if the value of this parameter is significantly greater than 1, then it is concluded that the number of crashes were increased after signal timing. The methodology provides for estimation of the full distribution of the parameter of interest for each intersection.

Significance is determined by how much of a distribution covers the null value of 1. Standard practice usually dictates that if the null value falls in the lower or upper tails of the distribution, say 5 percent, then the result is considered significant and the number of crashes is determined to have changed significantly after signal timing. For this study, if the null value of 1 falls in the upper 10 percent of the distribution, then it will be concluded that the numbers of crashes for an intersection were reduced significantly after signal timing since the average value or median value of the distribution will be less than 1. Similarly, if the null value of 1 falls in the lower 10 percent of the distribution, then it will be concluded that the number of crashes increased after signal timing since the average or median value of the distribution will be greater than 1. Stated another way, if the 90th percentile of a distribution is less than 1, then it is concluded that the numbers of crashes were reduced significantly after signal timing. If the 10th percentile of the distribution is greater than 1, then it is concluded that the numbers of crashes were increased significantly after signal timing. Intersections whose distributions satisfy this decision rule will be called *strongly* significant.

The criterion stated above is fairly strict, in the sense that overwhelming evidence is required for the number of crashes after signal timing to be declared significant. A good number of the intersections in this study show clear trends or patterns of change after signal timing even though they do not meet the definition of significance in the strict sense defined above. To identify these intersections, a second decision rule is introduced that relaxes the criterion from the 10th and 90th percentiles to the 25th and 75th percentiles. Intersections whose distributions satisfy this relaxed criterion will be called *mildly* significant. Under this definition, if the null value of 1 falls between the 75th and the 90th percentiles of the distribution, then it will be concluded that some possibility exists that the number of crashes decreased mildly after the intervention. If the null value of 1 falls between the 10th and the 25th percentiles of the distribution, it will be concluded that the number of crashes increased mildly. These intersections are highlighted as candidate intersections whose numbers of crashes may have changed after signal timing.

A boxplot is a useful graphical tool for displaying the shape of a distribution. The *box* represents the middle 50 percent of the distribution, while the line inside the box represents the median (50th percentile). The *whiskers* of the boxplot (dotted lines) to the right and left of the box represent the upper 25 percent and lower 25 percent of the distribution, respectively. In this study, side-by-side boxplots of the distributions for the parameters of interest are shown in relation to the null value of 1 for the intersections on each corridor. Strong significance and mild significance can be determined from these boxplots.

Although one model is fit to all 130 intersections in order to adjust the estimation of parameters, results for each of the five corridors are presented separately. The next five sections are devoted to results on Ford Road (M-153), Plymouth Road (Old M-14), Jefferson Avenue, Hall Road (M-59), and Woodward Avenue (M-1), in that order. The presentation for each corridor follows a similar format. First, a table shows the numbers of crashes and numbers of days for each intersection before and after signal timing. Percentiles, which can be used to assess significance, are shown for the parameter of interest. Second, side-by-side boxplots are displayed for visually comparing the relative significance of each intersection. Finally, overall statistics including injury severity, time of day, day of the week, and crash type are shown for each corridor.

4. Results for Ford Road (M-153)

The numbers of crashes before and after signal timing were recorded for the 26 intersections on Ford Road (M-153) that are under investigation in this study. The length of this corridor is approximately 13.2 miles, making it the longest of the five corridors, and the date of signal timing for all intersections on Ford Road was May 1, 2004. The calculated number of days for counting crashes during the before period, based on the beginning evaluation date of January 1, 2001, is 1,217 days. Similarly, the calculated number of days for counting crashes during the after period, based on the ending evaluation date of December 31, 2005, is 609 days. Note that the before period is approximately twice as long as the after period. Intuitively, for an intersection to attain significance, the number of crashes during the after period should be less than half the number during the before period, although significance is determined by a statistical model that fits and adjusts for effects based on all 130 intersections.

Table 3 shows numbers of before crashes, after crashes, before days, and after days for the 26 intersections on Ford Road. Each intersection gives rise to the full distribution of the parameter used to determine if the number of crashes changed after signal timing. The last five columns of Table 3 show the 10^{th}, 25^{th}, 50^{th} (median), 75^{th}, and 90^{th} percentiles of the parameter of interest. Values in these columns can be used to judge significance. For example, if the 10^{th} percentile is greater than 1, then the number of crashes increased significantly on that intersection after signal timing. If the 90^{th} percentile is less than 1, then the number of crashes decreased significantly on that intersection after signal timing. While *strong* significance is determined from the 10^{th} and 90^{th} percentiles, *mild* significance can be determined from the 25^{th} and 75^{th} percentiles. Intersections that attain significance are highlighted in Table 3. The 50^{th} percentile is the median and shows the middle of the distribution.

On Ford Road, four intersections show strong reductions in the numbers of crashes after signal timing. The four intersections are Henry Ruff, Brandt, Middlebelt, and Inkster. Note that the numbers of *after* crashes for each of these intersections are well less than half of the *before* numbers. Since the intersections in Table 3 are ordered from west to east, it is also clear that the strongly significant intersections are grouped closely by spatial location. Two other intersections, Beech Daly and Rouge, attain mild significance since the 75^{th} percentiles are less than 1, but the 90^{th} percentiles are not. The intersections Merriman, Outer Drive, and Golfview nearly attain

Table 3. Significance of Signal Timing on Ford Road

	Intersection	Before Crashes	After Crashes	Before Days	After Days	10%	25%	50%	75%	90%
1	Beck	69	50	1217	609	1.015	1.106	1.219	1.343	1.468
2	Canton	137	103	1217	609	1.152	1.232	1.333	1.441	1.547
3	Sheldon	142	80	1217	609	0.927	0.997	1.077	1.166	1.251
4	Morton	78	39	1217	609	0.821	0.900	0.992	1.093	1.191
5	Lotz	63	47	1217	609	1.020	1.115	1.232	1.363	1.494
6	Wal-Mart	19	6	1217	609	0.705	0.799	0.913	1.039	1.164
7	Hix	110	60	1217	609	0.887	0.959	1.047	1.145	1.242
8	Newburgh	168	100	1217	609	0.982	1.049	1.130	1.217	1.301
9	Carlson	74	40	1217	609	0.860	0.940	1.037	1.143	1.248
10	Wayne	256	128	1217	609	0.880	0.934	0.996	1.062	1.124
11	Wildwood	62	34	1217	609	0.854	0.937	1.037	1.148	1.263
12	Venoy	53	28	1217	609	0.823	0.912	1.017	1.132	1.246
13	Merriman	145	65	1217	609	0.789	0.850	0.923	1.002	1.078
14	Henry Ruff	129	44	1217	609	0.659	0.720	0.791	0.868	0.941
15	Brandt	67	18	1217	609	0.610	0.683	0.770	0.859	0.948
16	Middlebelt	178	67	1217	609	0.701	0.755	0.818	0.887	0.951
17	Harrison	46	21	1217	609	0.771	0.853	0.955	1.066	1.185
18	Inkster	197	80	1217	609	0.739	0.794	0.859	0.928	0.992
19	John Daly	98	56	1217	609	0.906	0.983	1.074	1.178	1.281
20	Beech Daly	184	79	1217	609	0.772	0.829	0.896	0.966	1.031
21	Gulley	63	37	1217	609	0.888	0.973	1.075	1.188	1.303
22	Silvery	51	36	1217	609	0.962	1.052	1.169	1.300	1.432
23	Telegraph	201	107	1217	609	0.912	0.972	1.043	1.120	1.194
24	Outer Drive	72	30	1217	609	0.745	0.820	0.911	1.007	1.101
25	Rouge	29	7	1217	609	0.650	0.735	0.840	0.954	1.065
26	Golfview	110	48	1217	609	0.768	0.836	0.917	1.004	1.087

mild significance because the 75th percentiles are almost, but not quite, less than 1. Three intersections, Beck, Canton, and Lotz, show significant increases in the numbers of crashes after signal timing. It is clear that these three intersections also group together geographically at the west end of the corridor. Two intersections, Newburgh and Silvery, show mild increases in crashes after signal timing since the 25th percentiles are greater than 1, but the 10th percentiles are not. Note that Sheldon, which is located very close to the three strongly significant intersections, almost attains mild significance because the 25th percentile is very close to 1.

The side-by-side boxplots in Figure 1 show the full distributions of the parameter of interest for each intersection on Ford Road. Each boxplot can be judged in relation to its spread about the null value 1. Intersections with large numbers of crashes tend to have the tightest distributions, while intersections with few crashes tend to be more variable. For example, the Wayne intersection (intersection 10), which has a total of 384 crashes, has a tight distribution compared to the Wal-Mart intersection (intersection 6) which has a total of 25 crashes. Figure 1 shows clear groupings of the strongly significant intersections. Henry Ruff, Brandt, Middlebelt, and

Inkster are intersections 14, 15, 16, and 18, respectively. Beck, Canton, and Lotz are intersections 1, 2, and 5, respectively. It is interesting to note that Brandt (intersection 15) has the smallest median, but Henry Ruff (intersection 14) has the smallest 90th percentile. Note that the sample size, which is the number of crashes, is larger for Henry Ruff, giving it a tighter distribution.

Figure 1. Boxplots for Intersections on Ford Road (M-153)

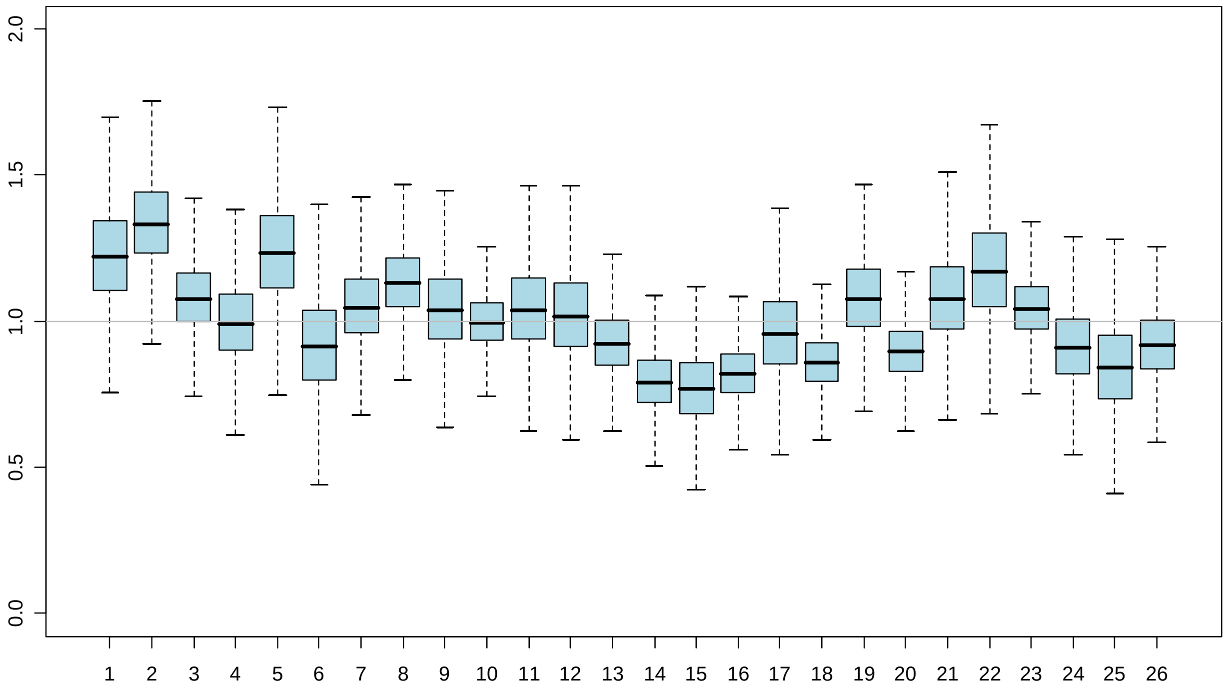


Table 4 shows summary statistics for the intersections on Ford Road before and after signal timing. The table shows distributions for injury severity, time of day, day of the week, and crash type. Judging by percentages, the distributions do not appear to have changed much after signal timing. About 78 percent of the crashes result in property damage only, and about 50 percent are rear-end crashes. Most of the crashes occur during the daytime, but the distributions before and after signal timing are very similar. About 40 percent of the crashes occur between 10:00 a.m. to 3:59 p.m., and about 29 percent occur between 4:00 to 7:59 p.m. It is unclear if the number of crashes increased from 12.7 percent to 16 percent between 8:00 a.m. to 5:59 p.m. during the after period since 9.4 percent of the data are not recorded during the before period for time of day. Crashes are fairly uniformly distributed according to day of the week, except the fewest crashes tend to occur on Sunday, and the most tend to occur on Friday. Appendix B displays these tables for each intersection separately.

The 26 intersections had 2,801 crashes before the signal timing effort, and about half that many, or 1,410, after. Based on these numbers, it does not appear that the total numbers of crashes were reduced on this corridor since the after period is about half that of the before period. Appendix C outlines a method for conducting a large sample test to determine whether the numbers of crashes were reduced after signal timing on a corridor overall. Since the numbers of crashes on corridors are generally large, in this case in the thousands, the large sample test is used. A Z-statistic is calculated and the decision rule is to reject the hypothesis of no change in the number of crashes after signal timing if the Z-statistic is less than -1.96 or if it is greater than 1.96. On Ford Road, Z = -0.18, leading to the decision that there was no significant change in the number of crashes on this corridor overall after signal timing.

Table 4. Summary Statistics for Ford Road (M-153)

Injury Severity	Before	%	After	%
Fatal	1	0.0	0	0.0
A-Injury	48	1.7	15	1.1
B-Injury	115	4.1	55	3.9
C-Injury	463	16.5	233	16.5
O-Injury	2,174	77.6	1,107	78.5
Total	2,801	100.0	1,410	100.0

Time of Day	Before	%	After	%
6am - 9:59am	337	12.0	178	12.6
10am - 3:59pm	1,062	37.9	587	41.6
4pm - 7:59pm	783	28.0	417	29.6
8pm - 5:59am	355	12.7	225	16.0
Unknown	264	9.4	3	0.2
Total	2,801	100.0	1,410	100.0

Day of Week	Before	%	After	%
Sunday	234	8.4	122	8.7
Monday	416	14.9	198	14.0
Tuesday	419	15.0	196	13.9
Wednesday	427	15.2	228	16.2
Thursday	399	14.2	206	14.6
Friday	504	18.0	276	19.6
Saturday	402	14.4	184	13.0
Total	2,801	100.0	1,410	100.0

Crash Type	Before	%	After	%
Single vehicle	83	3.0	51	3.6
Head-on	293	10.5	129	9.1
Angle	623	22.2	336	23.8
Rear-end	1,407	50.2	695	49.3
Sideswipe	263	9.4	166	11.8
Other/unknown	132	4.7	33	2.3
Total	2,801	100.0	1,410	100.0

5. Results for Plymouth Road (Old M-14)

The presentation for Plymouth Road (Old M-14) follows closely the same format shown in the previous section. Eighteen intersections are under investigation on this corridor which is approximately 6.7 miles in length. Since the completion date of signal timing on Plymouth Road is the same as that on Ford Road, the calculated number of days for counting crashes during the before and after periods are also the same. Table 5 shows the relevant statistics for assessing significance of the signal timing intervention. Three intersections show strong reductions in the numbers of crashes after signal timing. The 90th percentiles for Levan, Merriman, and Middlebelt are less than 1, suggesting the numbers of crashes decreased significantly on these intersections. In addition to these three, seven intersections show mild reductions after signal timing. These intersections include Ann Arbor, Ford Transmission, Wayne, Milburn Sears, Harrison, Deering, and Dixie. Deering is very close to strong significance, but does not quite attain it.

One may wonder why an intersection such as Harrison, with 19 crashes before signal timing and seven crashes after signal timing, attains mild significance, while the Wal-Mart intersection on

Ford Road (Table 3), with 19 crashes before signal timing and six crashes after signal timing, does not. Even though the before and after days are the same for Ford Road and Plymouth Road, the model that is used to test for significance adjusts for effects due to corridor. Intersections on different corridors are not treated independently. It should also be stressed that intersections that attain *mild* significance should be judged accordingly. These intersections are presented for consideration as intersections whose numbers of crashes possibly changed after signal timing. The intersections that attain *strong* significance are the ones that show significant change after signal timing.

Table 5. Significance of Signal Timing on Plymouth Road (Old M-14)

	Intersection	Before Crashes	After Crashes	Before Days	After Days	10%	25%	50%	75%	90%
1	Ann Arbor	8	2	1217	609	0.633	0.721	0.835	0.962	1.092
2	Levan	89	24	1217	609	0.560	0.622	0.693	0.769	0.845
3	Ford Trans.	18	7	1217	609	0.661	0.744	0.852	0.973	1.092
4	Wayne	99	46	1217	609	0.756	0.824	0.903	0.990	1.078
5	Stark	64	52	1217	609	1.009	1.107	1.228	1.362	1.497
6	Farmington	119	58	1217	609	0.790	0.855	0.932	1.018	1.101
7	Hubbard	13	7	1217	609	0.699	0.789	0.901	1.031	1.172
8	Merriman	186	57	1217	609	0.586	0.633	0.688	0.748	0.805
9	Milburn Sears	33	12	1217	609	0.650	0.729	0.825	0.935	1.045
10	Tech Center	38	18	1217	609	0.711	0.794	0.894	1.008	1.125
11	Middlebelt	182	67	1217	609	0.664	0.715	0.774	0.838	0.900
12	Harrison	19	7	1217	609	0.651	0.736	0.843	0.965	1.089
13	Deering	24	6	1217	609	0.600	0.683	0.781	0.892	1.004
14	Inkster	99	47	1217	609	0.764	0.832	0.913	1.003	1.090
15	Hemingway	25	15	1217	609	0.753	0.842	0.954	1.081	1.216
16	Beech Daly	111	57	1217	609	0.813	0.881	0.965	1.054	1.141
17	Dixie	20	8	1217	609	0.662	0.748	0.855	0.974	1.099
18	Telegraph	172	88	1217	609	0.844	0.905	0.975	1.054	1.129

Only one intersection shows a strong increase in crashes after signal timing. The 10^{th} percentile for Stark is greater than 1, suggesting that the number of crashes actually increased on this intersection after the intervention. On Stark, there were 64 crashes before signal timing and 52 after.

Figure 2 shows boxplots for assessing significance of the intersections on Plymouth Road. The value of the boxplots is that they show the full distributions of the parameter of interest for each intersection. The plots are ordered from west to east and show variability and general trends. Note that when the numbers of crashes are large, such as for Merriman, Middlebelt, and Telegraph, the boxplots are tight. When the numbers of crashes are smaller, as for Hubbard and Harrison, the variability in the plots is greater. Except for Stark, the estimated medians, indicated by the solid lines in the centers of the boxes, are all less than 1. This suggests that on Plymouth Road there is a general trend of crash reduction after the intervention for this corridor in general.

The boxplots for Levan and Merriman are entirely below 1, and the boxplot for Middlebelt is almost entirely below 1. These are the intersections that show strong reductions in crashes after signal timing.

Figure 2. Boxplots for Intersections on Plymouth Road (Old M14)

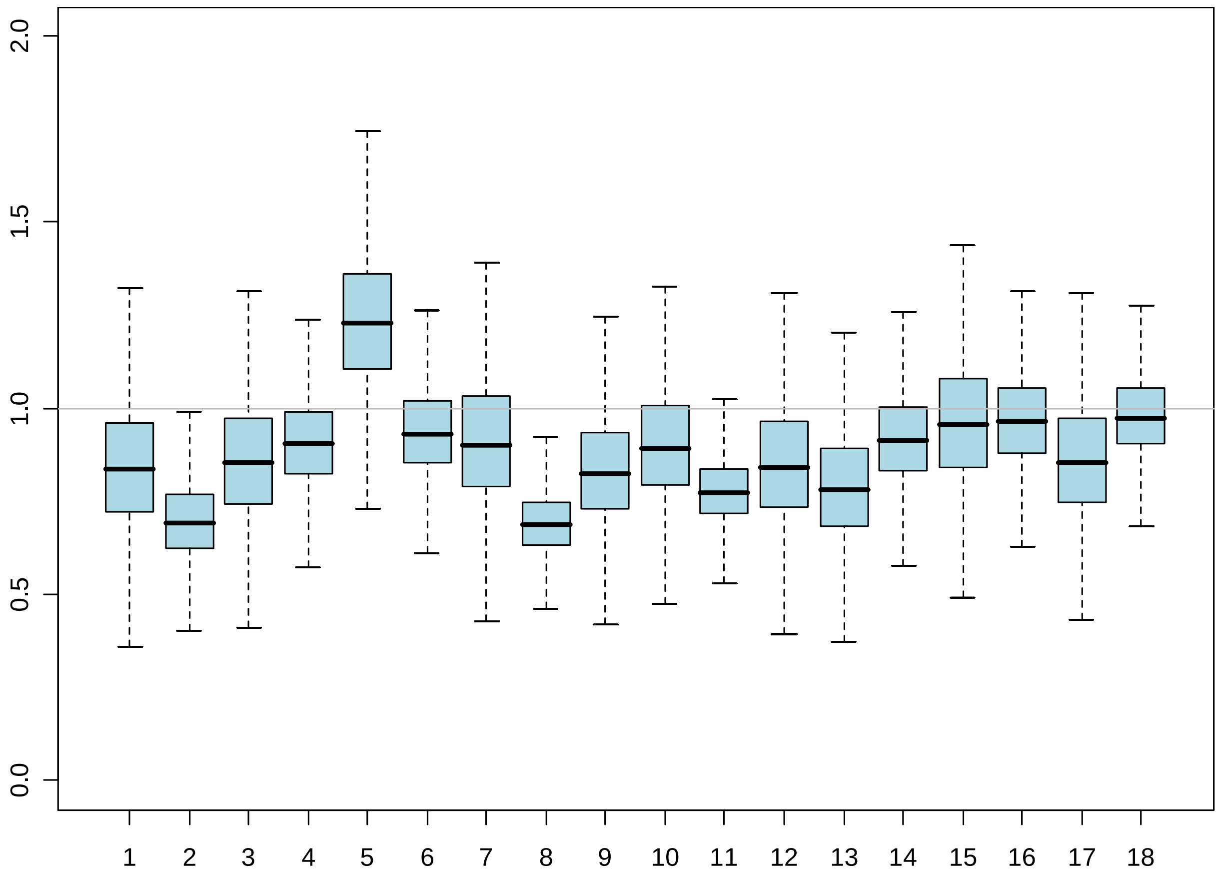


Table 6 shows distributions of injury severity, time of day, day of week, and crash type for the intersections on Plymouth Road before and after signal timing. As for Ford Road (Table 4), and all intersections (Table 1), about 78 to 79 percent of the crashes are property damage only, and about half are rear-end type crashes. Numbers of crashes are reduced on Sunday, and somewhat elevated on Friday, but before and after percentages do not differ greatly. About 41 to 44 percent of the crashes occur between 10:00 a.m. and 3:59 p.m., and about 29 percent occur between 4:00 p.m. and 7:59 p.m., but before and after percentages are similar. These patterns closely follow those found on Ford Road. It seems that these distributions did not change significantly after signal timing.

There were 1,319 crashes before signal timing and 578 after. The large sample statistical test outlined in Appendix C is a test for determining whether the number of crashes changed on a corridor after signal timing. The test takes into account numbers of before and after crashes, and numbers of before and after days. If the Z-statistic described in Appendix C is less than -1.96 or if it is greater than 1.96, then the hypothesis of no change is rejected. Since Z = 2.66, the hypothesis of no change is rejected and it is concluded that on Plymouth Road the overall number of crashes decreased significantly after signal timing.

Table 6. Summary Statistics for Plymouth Road (Old M-14)

Injury Severity	Before	%	After	%
Fatal	0	0.0	2	0.3
A-Injury	13	1.0	7	1.2
B-Injury	53	4.0	20	3.5
C-Injury	211	16.0	96	16.6
O-Injury	1,042	79.0	453	78.4
Total	1,319	100.0	578	100.0

Time of Day	Before	%	After	%
6am - 9:59am	176	13.3	82	14.2
10am - 3:59pm	545	41.3	254	43.9
4pm - 7:59pm	372	28.2	169	29.2
8pm - 5:59am	137	10.4	70	12.1
Unknown	89	6.7	3	0.5
Total	1,319	100.0	578	100.0

Day of Week	Before	%	After	%
Sunday	81	6.1	34	5.9
Monday	222	16.8	85	14.7
Tuesday	201	15.2	92	15.9
Wednesday	213	16.1	115	19.9
Thursday	204	15.5	79	13.7
Friday	258	19.6	98	17.0
Saturday	140	10.6	75	13.0
Total	1,319	100.0	578	100.0

Crash Type	Before	%	After	%
Single vehicle	44	3.3	16	2.8
Head-on	77	5.8	40	6.9
Angle	346	26.2	161	27.9
Rear-end	656	49.7	270	46.7
Sideswipe	148	11.2	75	13.0
Other/unknown	48	3.6	16	2.8
Total	1,319	100.0	578	100.0

6. Results for Jefferson Avenue

On Jefferson Avenue there are only ten intersections under investigation and this corridor, measuring approximately one-third of a mile, is by far the shortest. These intersections are located in the downtown area of Detroit on a corridor that runs parallel to the waterfront. The intersections are located closely together and many of the crashes occurred within 50 or 100 feet of the centers of the intersections (see the supplement document, Appendix B). Of the five corridors examined in this study, the intersections on Jefferson Avenue showed the strongest reductions in the numbers of crashes after signal timing.

As Table 7 shows, seven of the ten intersections show strong reductions in the numbers of crashes and two intersections show mild reductions. Jefferson Avenue runs east and west and is divided by a grassy median. For each intersection in Table 7, traffic flows in either the west or east direction. For example, GriswoldWest refers to the intersection located at Jefferson and Griswold Street where traffic flows westbound on Jefferson. Similarly, GriswoldEast refers to the intersection located at Jefferson and Griswold Street where traffic flows in the eastbound direction. The intersection WBJeffNBWood refers to the intersection located at westbound Jefferson and northbound Woodward. The other intersections are interpreted similarly. Since these ten intersections are located closely together, and the names in Table 7 are somewhat cryptic, Figure 3 and Figure 4 show the locations of the intersections described in Table 7. In addition, the maps in Appendix B show crashes on these intersections.

Table 7. Significance of Signal Timing on Jefferson Avenue

	Intersection	Before Crashes	After Crashes	Before Days	After Days	10%	25%	50%	75%	90%
1	GriswoldWest	60	31	1131	695	0.615	0.677	0.755	0.842	0.929
2	GriswoldEast	39	26	1131	695	0.665	0.738	0.829	0.932	1.042
3	WBJeff NBWood	43	21	1131	695	0.583	0.648	0.728	0.821	0.914
4	WBJeffSBWood	73	11	1131	695	0.373	0.423	0.482	0.545	0.605
5	EBJeffWood	64	38	1131	695	0.669	0.736	0.819	0.910	1.004
6	RandolphWest	62	32	1131	695	0.618	0.681	0.759	0.848	0.933
7	RandolphEast	151	63	1131	695	0.580	0.628	0.684	0.743	0.802
8	WBJeffBrush	30	4	1131	695	0.423	0.486	0.560	0.644	0.726
9	BeaubienWest	38	31	1131	695	0.730	0.810	0.914	1.030	1.147
10	BeaubienEast	89	21	1131	695	0.425	0.474	0.531	0.592	0.652

Figure 3. Location of Intersections 1-5 on Jefferson Avenue

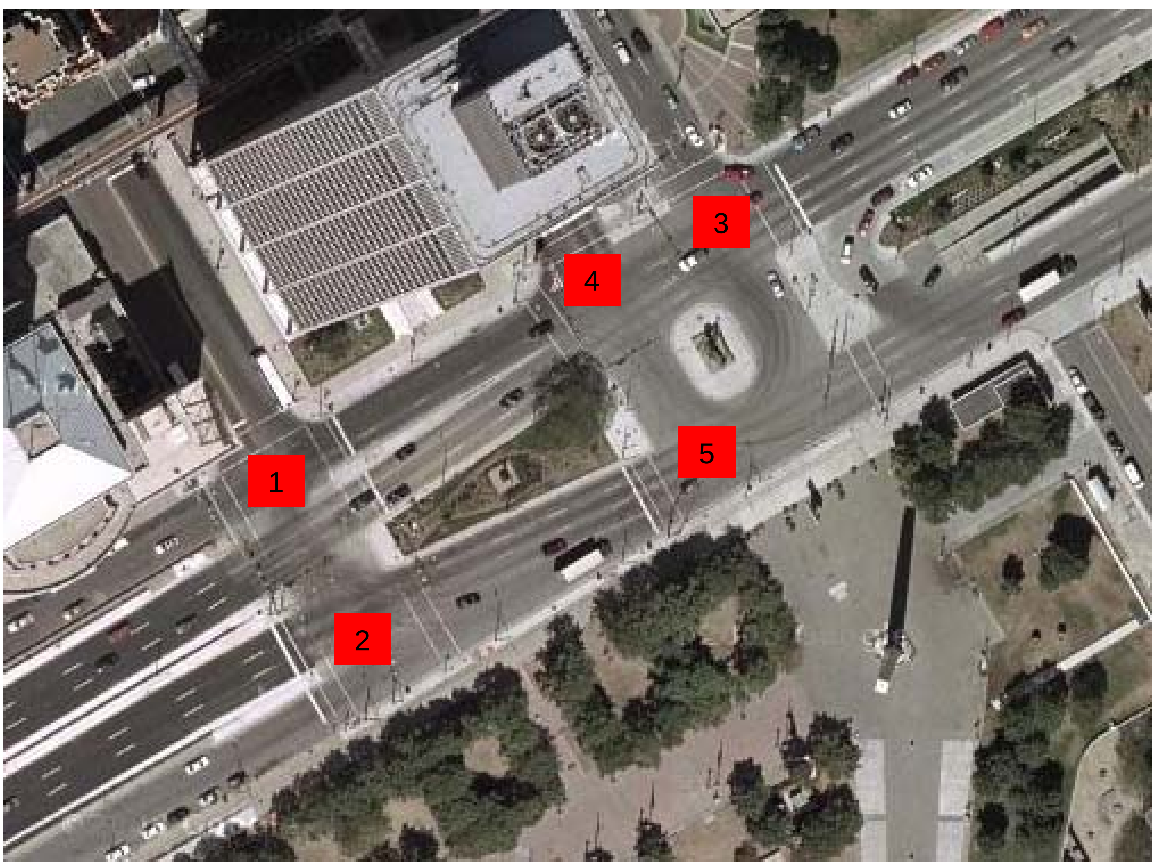
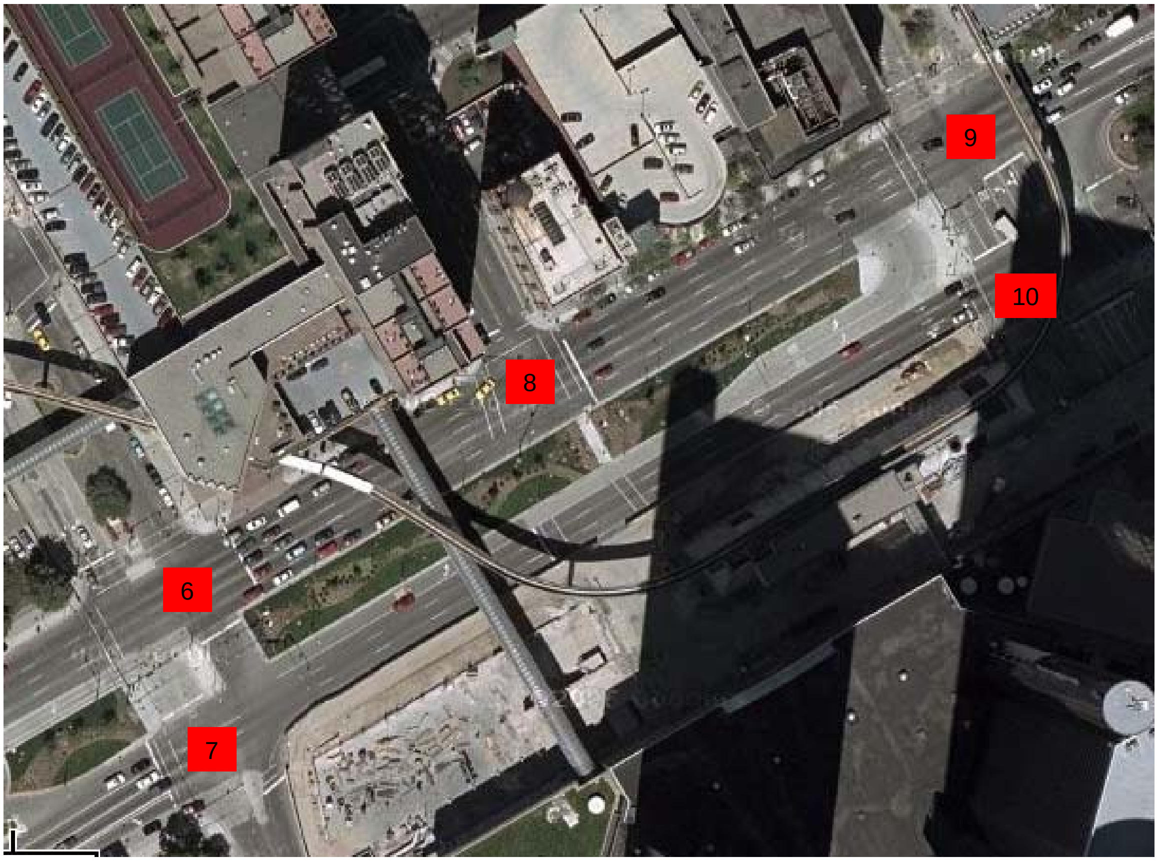


Figure 4. Location of Intersections 6-10 on Jefferson Avenue



Note the close proximity of these intersections and the dependence between them. Several intersections permit left or right turns that affect oncoming traffic from other intersections. The intersections 1, 3, and 4 in Figure 3 are strongly significant and these are in the westbound direction on Jefferson Avenue near Griswold and Woodward. On the other hand, intersections 2 and 5 are only mildly significant and these are in the eastbound direction near Griswold and Woodward. Again, mild significance should be judged with caution. The model used to test for significance contains corridor-specific effects and, because this is a corridor with strong effects overall, all intersections on this corridor are influenced by a Jefferson Avenue effect. This is how intersections 2 and 5 attain mild significance, but they are not strongly significant. Also note that 695 days is the longest after period of all five corridors. Signal timing for this intersection occurred on February 5, 2004.

Of intersections 6 through 10 shown in Figure 4, all are strongly significant except intersection 9 which is on westbound Jefferson at Beaubien Street. Randolph Street at eastbound Jefferson, intersection 7, had a lot of crashes before signal timing. Of the ten intersections on Jefferson Avenue, this intersection has the most crashes.

Figure 5 shows the boxplots for the ten intersections on Jefferson Avenue. A clear trend shows that all of the boxplots have medians less than 1. The boxplots for intersections 4, 7, 8, and 10 are entirely below the value 1, demonstrating very strong significance for these intersections. Intersections 4 and 10 are the most strongly significant, suggesting that these two intersections show the strongest reductions in the numbers of crashes after signal timing on Jefferson Avenue. Intersection 9 shows no significance since the value 1 intersects the box, and intersections 2 and 5 show weak significance, if any at all.

Figure 5. Boxplots for Intersections on Jefferson Avenue

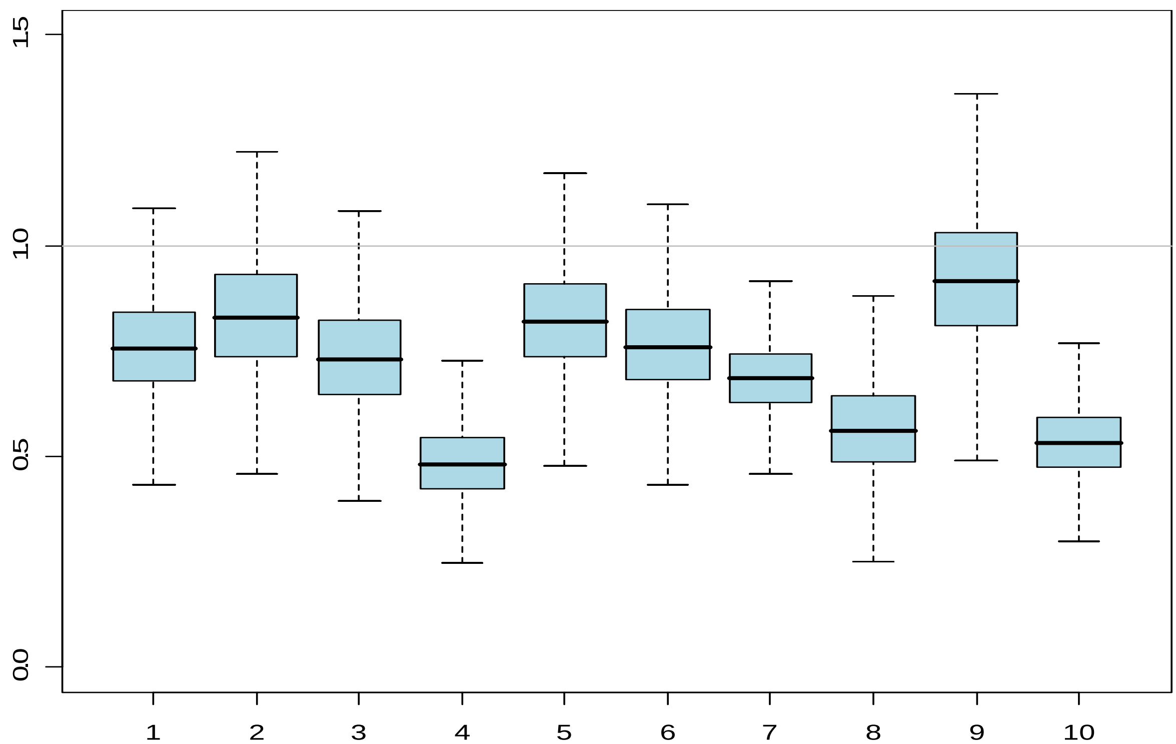


Table 8 shows summary statistics for the intersections on Jefferson Avenue according to injury severity, time of day, day of week, and crash type. Distributions are presented before and after signal timing and are slightly different than those on other corridors in this study. Due to the confined nature of this corridor in the downtown area, speeds are probably reduced on these intersections, resulting in crashes with less injury severity overall. This seems to be the case since about 85 to 88 percent of the crashes result in property damage only. While most of the crashes on this corridor are rear-end type crashes, unlike other corridors, almost an equal amount are sideswipe type crashes. This could be due to the one-way flow of traffic on either side of Jefferson Avenue. In comparison to the other corridors, this corridor also shows elevated numbers of crashes at night time, possibly due to night time activities or the close proximity to the tunnel to Canada. As on other corridors, numbers of crashes are elevated on Friday. Some minor differences in distributions may be present before and after signal timing, but there do not appear to be major shifts in the distributions of these variables.

On the Jefferson corridor, the overall number of crashes is 649 before signal timing and 278 after. Using the large sample test outlined in Appendix C, the Z-statistic for testing if the number of crashes changed after signal timing is 5.06. Since 5.06 is greater than 1.96, the hypothesis is rejected and it is concluded that the overall number of crashes was reduced significantly on Jefferson Avenue. Of all the corridors evaluated based on this Z-test, the result on Jefferson Avenue is the most significant, with the largest reduction in the number of crashes.

Table 8. Summary Statistics for Jefferson Avenue

Injury Severity	Before	%	After	%
Fatal	1	0.2	0	0.0
A-Injury	5	0.8	3	1.1
B-Injury	15	2.3	4	1.4
C-Injury	80	12.3	26	9.4
O-Injury	548	84.4	245	88.1
Total	649	100.0	278	100.0

Time of Day	Before	%	After	%
6:00 a.m. - 9:59 a.m.	89	13.7	49	17.6
10:00 a.m. - 3:59 p.m.	208	32.0	76	27.3
4:00 p.m. - 7:59 p.m.	153	23.6	82	29.5
8:00 p.m. - 5:59 a.m.	157	24.2	65	23.4
Unknown	42	6.5	6	2.2
Total	649	100.0	278	100.0

Day of Week	Before	%	After	%
Sunday	79	12.2	26	9.4
Monday	83	12.8	37	13.3
Tuesday	87	13.4	47	16.9
Wednesday	91	14.0	47	16.9
Thursday	90	13.9	28	10.1
Friday	124	19.1	52	18.7
Saturday	95	14.6	41	14.7
Total	649	100.0	278	100.0

Crash Type	Before	%	After	%
Single vehicle	31	4.8	10	3.6
Head-on	9	1.4	6	2.2
Angle	103	15.9	41	14.7
Rear-end	231	35.6	106	38.1
Sideswipe	207	31.9	105	37.8
Other/unknown	68	10.5	10	3.6
Total	649	100.0	278	100.0

7. Results for Hall Road (M-59)

The intersections on Hall Road (M-59) are located in Macomb County, east of the city of Pontiac. This is the only corridor considered in this study located outside of Wayne County. There are 28 intersections under investigation on Hall Road, and the corridor spans a distance of approximately 7.5 miles. The traffic flows east and west and there is a median separating the eastbound and westbound traffic. Depending on location, the median is between approximately 100 and 200 feet wide. For some of the intersections, interest focuses on traffic signals controlling four-legged intersections, but for many of the intersections, interest focuses only on traffic signals controlling either the westbound or eastbound traffic.

Figure 6 shows an overhead view of a representative section on Hall Road. Two intersections are highlighted in the figure. Intersection 1 is Hall Road and Schoenherr Road and clearly shows that traffic flows east and west on Hall Road, and north and south on Schoenherr Road. The figure also displays the median and the divided nature of the roadways. Intersection 2 is described as the M-59 eastbound crossover west of Schoenherr. Traffic only flows in the eastbound direction at this intersection. Figure 6 illustrates the point that some intersections cover both the eastbound and westbound directions, while other intersections only cover the eastbound or westbound direction, and may be located at crossovers, which are some distance away from the main intersection.

Figure 6. Hall Road (M-59) and Schoenherr Road (1) and Hall Road and the Eastbound Crossover West of Schoenherr (2)

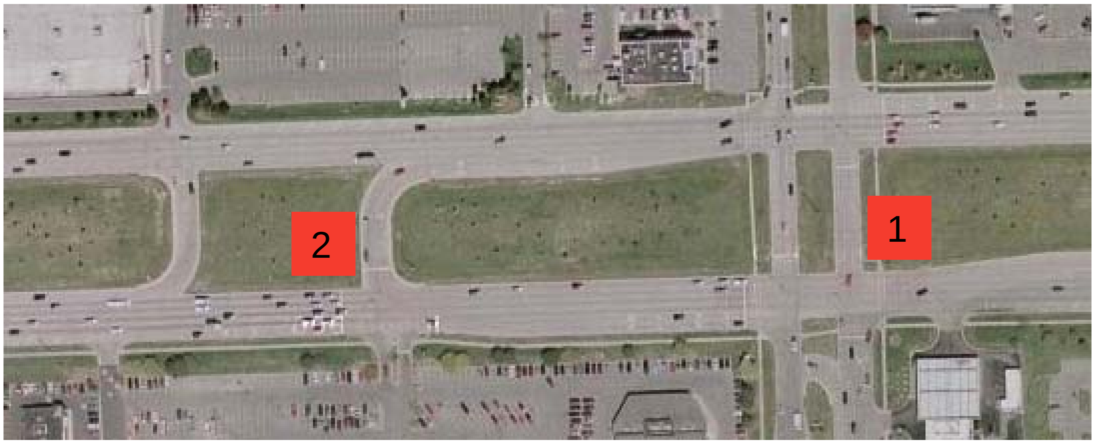
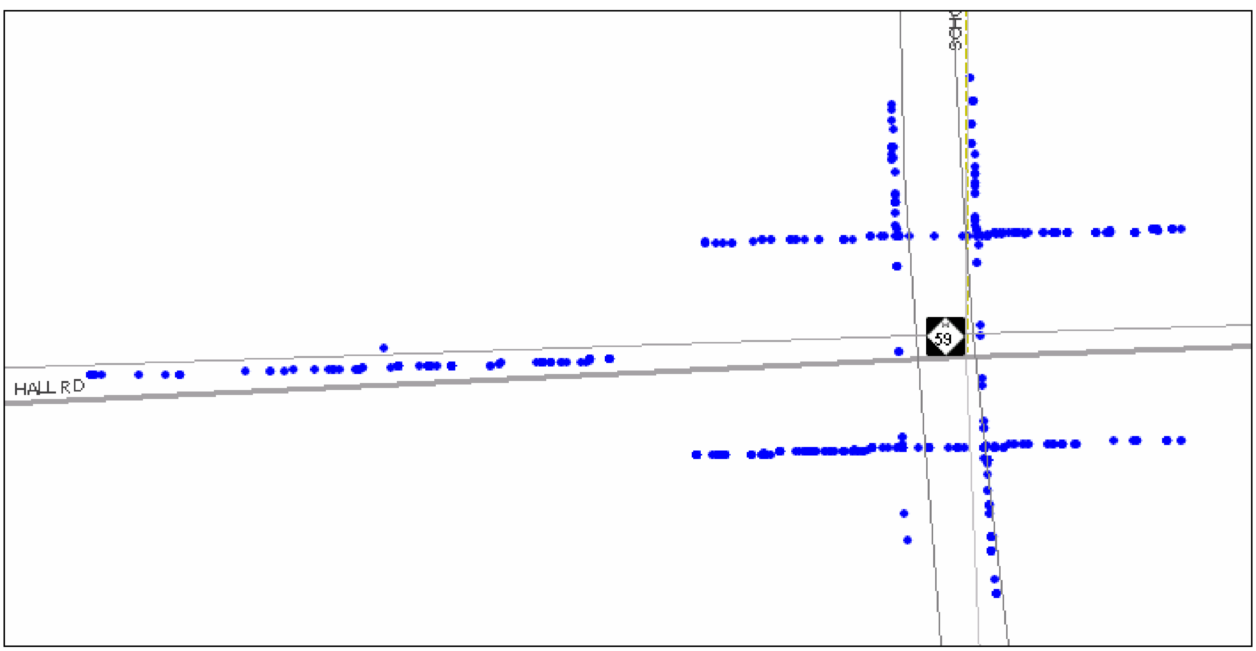


Figure 7 shows all the crashes, both before and after signal timing, that were geographically located using a spatial software analysis tool at the two intersections shown in Figure 6. Note that latitude and longitude coordinates are recorded accurately enough to distinguish the four directions of travel at Schoenherr Road. In addition, Figure 7 also shows the crashes

Figure 7. Crashes Geographically Located at Hall Road (M-59) and Schoenherr Road and Hall Road and the Eastbound Crossover West of Schoenherr



geographically located at the M-59 eastbound crossover west of Schoenherr. These crashes occurred only in the eastbound direction. For maps of the crashes before and after signal timing, see Appendix B.

Since some intersections on Hall Road cover crashes both eastbound and westbound at four-legged intersections, while other intersections only cover traffic proceeding in one direction on either side of the road, possibly at crossovers, Table 9 lists descriptions of all 28 intersections located on Hall Road. The intersections are ordered from west to east for clarity.

Table 9. Description of Intersections on Hall Road (M-59) from West to East

1	Eastbound crossover west of Van Dyke	15	Hayes
2	Van Dyke	16	Eastbound crossover west of Tilch
3	Westbound crossover at Custer	17	Eastbound crossover west of Garfield
4	Eastbound crossover west of Sterritt	18	Garfield
5	M53 Southbound off ramp	19	Westbound crossover east of Garfield
6	Eastbound and M53 Northbound off ramp	20	Eastbound crossover west of Romeo Plank
7	Delco	21	Romeo Plank
8	Westbound crossover east of Delco	22	Eastbound and Rivergate
9	Westbound crossover at Northpointe	23	Eastbound crossover west of Heydenreich
10	Eastbound crossover west of Schoenherr	24	Eastbound crossover west of Chateau Thierry
11	Schoenherr	25	Westbound crossover east of Chateau Thierry
12	Eastbound and Westbrook	26	Westbound and Card
13	Eastbound crossover at Eastbrook	27	Eastbound and Elizabeth
14	Eastbound crossover west of Hayes	28	Westbound crossover east of Elizabeth

Table 10 shows before and after crashes, before and after days, and percentiles of the distributions used for assessing significance of the signal timing procedure. Only one intersection on Hall Road shows a strong reduction in the number of crashes. The intersection labeled *Eastbound and M53 Northbound off ramp* (intersection 6 in Table 9) attains strong significance in reduced crashes since the 90th percentile is less than 1. No intersections attain mild significance in reduced crashes based on the 75th percentiles. On the other hand, seven intersections (5, 7, 9, 10, 17, 26, and 27) show strong increases in the numbers of crashes after signal timing. In addition, four intersections (2, 14, 15, and 21) show mild increases in the numbers of crashes after signal timing.

The general increase in the numbers of crashes on Hall Road is displayed by the boxplots shown in Figure 8. The boxplot for intersection 6 is the only one that falls well under the null value of 1. Other than intersection 6, no other boxplot has a median that appears to be much less than 1. Therefore, no other intersection comes close to even mild significance. At the other end, the boxplot for intersection 10 lies entirely above the null value of 1, indicating a strong increase in crashes at this intersection. In addition, the boxplots for intersections 7, 17, 26, and 27 all lie well above the value 1, demonstrating strong increases in the numbers of crashes.

Table 10. Significance of Signal Timing on Hall Road (M-59)

	Intersection	Before Crashes	After Crashes	Before Days	After Days	10%	25%	50%	75%	90%
1	EastVanDyke	6	0	1233	593	0.761	0.877	1.017	1.174	1.338
2	VanDyke	205	110	1233	593	0.975	1.037	1.114	1.195	1.274
3	WestCuster	18	8	1233	593	0.834	0.943	1.074	1.225	1.377
4	EastSterritt	41	16	1233	593	0.792	0.881	0.993	1.117	1.241
5	M53South	71	44	1233	593	1.000	1.092	1.201	1.323	1.445
6	EastM53North	47	7	1233	593	0.602	0.683	0.784	0.893	0.996
7	Delco	164	116	1233	593	1.196	1.275	1.371	1.473	1.571
8	WestDelco	17	10	1233	593	0.884	0.999	1.132	1.288	1.452
9	WestNorthpointe	71	46	1233	593	1.028	1.121	1.236	1.362	1.486
10	EastSchoenherr	66	73	1233	593	1.432	1.560	1.724	1.899	2.075
11	Schoenherr	360	180	1233	593	0.941	0.991	1.050	1.111	1.170
12	Westbrook	38	14	1233	593	0.773	0.871	0.988	1.110	1.231
13	Eastbrook	45	23	1233	593	0.876	0.976	1.091	1.221	1.350
14	EastHayes	17	14	1233	593	0.974	1.088	1.235	1.405	1.588
15	Hayes	247	128	1233	593	0.956	1.015	1.085	1.157	1.227
16	EastTilch	14	8	1233	593	0.874	0.988	1.127	1.283	1.445
17	EastGarfield	18	19	1233	593	1.067	1.194	1.352	1.539	1.731
18	Garfield	240	111	1233	593	0.870	0.927	0.993	1.063	1.130
19	WestGarfield	35	14	1233	593	0.802	0.898	1.015	1.143	1.275
20	EastRomeo	16	9	1233	593	0.872	0.986	1.121	1.281	1.443
21	Romeo	178	96	1233	593	0.971	1.040	1.122	1.206	1.286
22	Rivergate	23	8	1233	593	0.781	0.885	1.013	1.150	1.290
23	EastHeydenreich	8	4	1233	593	0.840	0.957	1.102	1.272	1.440
24	EastChateau	7	4	1233	593	0.855	0.972	1.119	1.284	1.462
25	WestChateau	16	4	1233	593	0.756	0.866	0.993	1.135	1.281
26	Card	60	45	1233	593	1.096	1.202	1.330	1.469	1.612
27	EastElizabeth	33	26	1233	593	1.042	1.149	1.291	1.449	1.610
28	WestElizabeth	5	0	1233	593	0.772	0.887	1.027	1.188	1.354

Hall Road is the only corridor in this study that shows a general increase in the numbers of crashes after signal timing. It was shown in Section 3.1 that the population in Macomb County increased between April 2000 and July 2006 by an estimated 6.2 percent. One explanation for the increasing trend in the numbers of crashes is that the 28 intersections are located in an area of Macomb County that is growing. The increase could be due to population density and traffic volume associated with community and economic development. This hypothesis is checked in Section 10, which addresses changes in average daily traffic (ADT) on the corridors before and after signal timing.

Figure 8. Boxplots of Intersections on Hall Road (M-59)

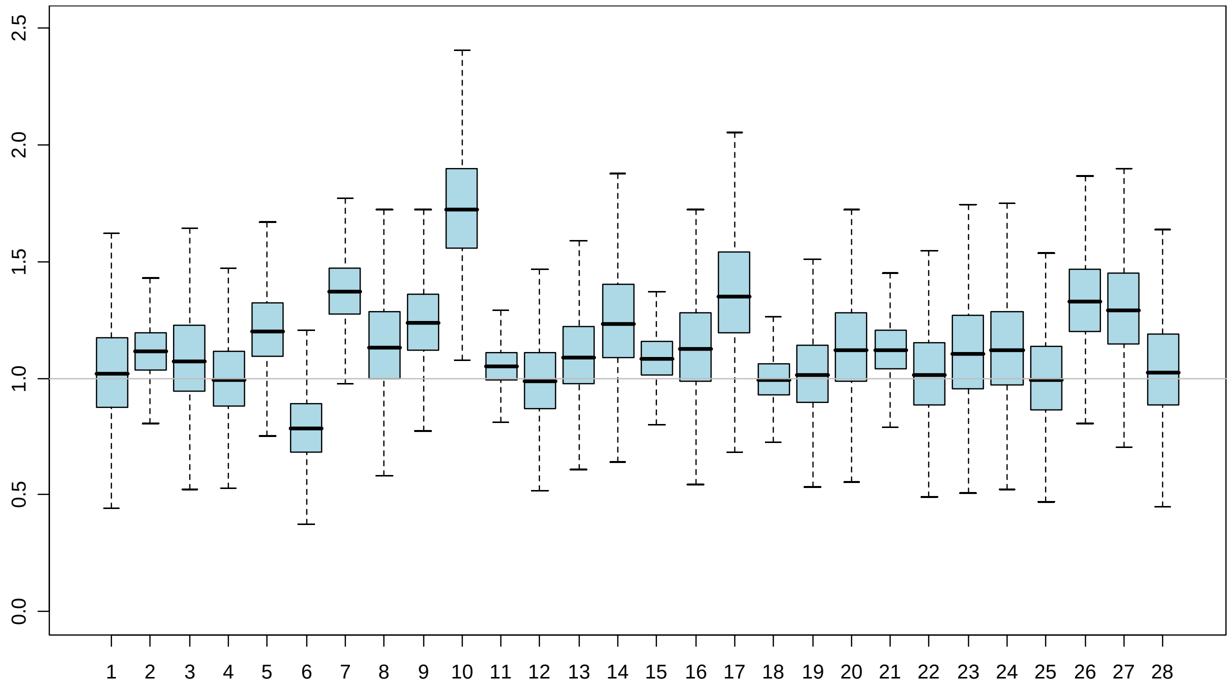


Table 11 shows distributions of injury severity, time of day, day of week, and crash type for Hall Road. As for the other corridors, there does not appear to be significant change in the distributions after signal timing. About 80 percent of the crashes involved property damage only. More than 60 percent of the crashes were rear-end types. The high percentage of rear-end crashes could be due to the divided highway that results in same-direction traffic on either side of the median. The configuration and high visibility afforded by Hall Road could limit the opportunity for head-on, angle, and sideswipe type crashes. Most crashes occur in the daytime and late afternoon, which generally agrees with results on other corridors. With respect to day of week, the crashes are fairly uniformly distributed, except that there are slightly more crashes on Friday and slightly fewer crashes on Sunday.

On Hall Road, the overall number of crashes before signal timing is 2,066 and the number after is 1,137. From Table 10, the number of before days is 1,233 and the number of after days is 593. Calculation of the Z-statistic described in Appendix C gives Z = -3.65 which is less than -1.96, meaning that the number of crashes overall on Hall Road changed significantly after signal timing. The negative sign attached to the Z-statistic indicates that the number of crashes increased. This is the only corridor of the five examined that shows a significant increase in crashes after signal timing.

Table 11. Summary Statistics for Hall Road (M-59)

Injury Severity	Before	%	After	%
Fatal	2	0.1	0	0.0
A-Injury	20	1.0	12	1.1
B-Injury	62	3.0	34	3.0
C-Injury	329	15.9	177	15.6
O-Injury	1,653	80.0	914	80.4
Total	2,066	100.0	1,137	100.0

Time of Day	Before	%	After	%
6am - 9:59am	243	11.8	165	14.5
10am - 3:59pm	832	40.3	509	44.8
4pm - 7:59pm	538	26.0	323	28.4
8pm - 5:59am	312	15.1	136	12.0
Unknown	141	6.8	4	0.4
Total	2,066	100.0	1,137	100.0

Day of Week	Before	%	After	%
Sunday	215	10.4	106	9.3
Monday	299	14.5	175	15.4
Tuesday	307	14.9	146	12.8
Wednesday	277	13.4	205	18.0
Thursday	269	13.0	160	14.1
Friday	375	18.2	184	16.2
Saturday	324	15.7	161	14.2
Total	2,066	100.0	1,137	100.0

Crash Type	Before	%	After	%
Single vehicle	54	2.6	29	2.6
Head-on	10	0.5	6	0.5
Angle	338	16.4	180	15.8
Rear-end	1,280	62.0	762	67.0
Sideswipe	321	15.5	141	12.4
Other/unknown	63	3.0	19	1.7
Total	2,066	100.0	1,137	100.0

8. Results for Woodward Avenue (M-1)

In this section, results for testing significance of signal timing on Woodward Avenue and some descriptive statistics are presented. In total, 48 intersections are under investigation on this corridor that spans a distance of approximately 8.2 miles. The intersections are presented in order from the northwest, beginning with State Fair entry gate 5, to the southeast, ending with Adams Avenue. Since there are 48 intersections, they are presented in two groups of 24 each. In addition, some of the intersections are located at crossovers or near ramps at service drives. Descriptions of these intersections by number are shown in Table 12.

Table 12. Descriptions of Intersections on Woodward Avenue Requiring Explanation

1	State Fair entry gate 5
2	State Fair bus loop
5	Northbound crossover south of 7 Mile
8	Merrill Plaisance
15	M8 (Davison) Westbound service drive
16	M8 (Davison) Eastbound service drive
40	Martin Luther King Jr. Blvd and Mack
44	I75 and Southbound service drive
45	I75 and Northbound service drive

Table 13 and Table 14 show numbers of before and after crashes, numbers of before and after days, and percentiles for assessing significance of signal timing. Only one intersection, State Fair, attains strong significance on this corridor. There were 72 crashes before the intervention and 15 after, making this intersection one that shows a strong reduction in the number of crashes

Table 13. Significance of Signal Timing on Woodward Avenue (first 24 intersections)

	Intersection	Before Crashes	After Crashes	Before Days	After Days	10%	25%	50%	75%	90%
1	State Fair gate 5	9	0	1356	470	0.637	0.730	0.846	0.973	1.107
2	State Fair bus loop	7	1	1356	470	0.676	0.771	0.891	1.027	1.175
3	State Fair	72	15	1356	470	0.628	0.701	0.786	0.883	0.973
4	7 Mile	39	14	1356	470	0.760	0.847	0.959	1.083	1.209
5	7 Mile South	11	1	1356	470	0.648	0.743	0.854	0.982	1.118
6	Grixdale	10	6	1356	470	0.774	0.877	1.006	1.157	1.321
7	Nevada	21	4	1356	470	0.661	0.751	0.859	0.979	1.100
8	Merrill	18	4	1356	470	0.674	0.767	0.878	1.006	1.141
9	6 Mile	118	32	1356	470	0.701	0.768	0.850	0.936	1.019
10	Pilgrim	40	10	1356	470	0.678	0.761	0.863	0.979	1.096
11	Sears	18	6	1356	470	0.721	0.815	0.930	1.068	1.208
12	Manchester	46	13	1356	470	0.704	0.787	0.891	1.001	1.115
13	Gerald	19	4	1356	470	0.671	0.761	0.871	0.998	1.127
14	Grand	15	4	1356	470	0.694	0.785	0.901	1.032	1.172
15	WB Davison	20	7	1356	470	0.731	0.825	0.940	1.071	1.207
16	EB Davison	28	13	1356	470	0.805	0.901	1.023	1.164	1.307
17	Buena	12	4	1356	470	0.718	0.813	0.934	1.073	1.216
18	Glendale	27	11	1356	470	0.773	0.866	0.983	1.119	1.258
19	Cortland	14	11	1356	470	0.862	0.968	1.110	1.276	1.457
20	Tuxedo	12	6	1356	470	0.755	0.856	0.984	1.131	1.284
21	Calvert	25	5	1356	470	0.658	0.748	0.857	0.974	1.094
22	Chicago	19	7	1356	470	0.739	0.831	0.948	1.084	1.229
23	Clairmount	51	10	1356	470	0.630	0.707	0.800	0.900	1.006
24	Hazelwood	42	13	1356	470	0.725	0.812	0.915	1.034	1.156

after signal timing. Note that of all the corridors, Woodward's completion date for signal timing of September 17, 2004 is the latest. This results in 1,356 days before signal timing, and 470 after. Relative to the other corridors, this requires that the number of crashes after signal timing must be considerably lower than before signal timing in order to attain significance. Note that Clairmount, intersection 23, nearly attains strong significance, but not quite.

Although only one intersection attains strong significance, a good number of intersections are mildly significant. In total, 15 or about one-third of the intersections on Woodward Avenue show mild reductions in the numbers of crashes after signal timing. Table 13 and Table 14 highlight these intersections. There appears to have been an overall mild reduction in the numbers of crashes on this corridor. Based on the 10th and 25th percentiles, none of the intersections show increases in the numbers of crashes after signal timing, either strongly or mildly.

Comparing intersections that are mildly significant with those that are not is one way to assess the sensitivity of the modeling procedure. For example, State Fair entry gate 5 with nine before crashes and zero after crashes is mildly significant, but State Fair bus loop with seven before crashes and one after crash is not. Similarly, Gerald with 19 before crashes and four after

Table 14. Significance of Signal Timing on Woodward Avenue (second 24 intersections)

	Intersection	Before Crashes	After Crashes	Before Days	After Days	10%	25%	50%	75%	90%
25	Euclid	41	12	1356	470	0.708	0.797	0.901	1.015	1.134
26	Seward	23	3	1356	470	0.628	0.713	0.820	0.936	1.058
27	Bethune	24	12	1356	470	0.811	0.908	1.034	1.178	1.334
28	Grand Blvd	65	27	1356	470	0.846	0.930	1.036	1.159	1.280
29	Milwaukee	44	11	1356	470	0.677	0.759	0.861	0.972	1.086
30	Baltimore	29	8	1356	470	0.696	0.787	0.897	1.019	1.144
31	Antoinette	15	10	1356	470	0.829	0.937	1.069	1.228	1.398
32	Palmer	32	15	1356	470	0.819	0.916	1.037	1.178	1.325
33	Kirby	32	15	1356	470	0.822	0.920	1.041	1.180	1.326
34	Putnam	47	9	1356	470	0.627	0.707	0.803	0.908	1.011
35	Warren	143	42	1356	470	0.736	0.801	0.877	0.961	1.043
36	Forest	50	17	1356	470	0.752	0.841	0.943	1.059	1.180
37	Canfield	50	11	1356	470	0.649	0.729	0.824	0.930	1.033
38	Alexandrine	59	19	1356	470	0.744	0.827	0.927	1.037	1.152
39	Parsons	28	13	1356	470	0.808	0.904	1.026	1.161	1.306
40	MLK	79	26	1356	470	0.763	0.842	0.935	1.040	1.144
41	Peterboro	24	9	1356	470	0.744	0.837	0.954	1.087	1.226
42	Charlotte	19	6	1356	470	0.711	0.804	0.923	1.055	1.196
43	Adelaide	12	2	1356	470	0.668	0.759	0.874	1.004	1.136
44	I75S	28	9	1356	470	0.726	0.815	0.929	1.055	1.187
45	I75N	20	10	1356	470	0.793	0.897	1.023	1.170	1.324
46	Montcalm	59	15	1356	470	0.681	0.757	0.851	0.956	1.061
47	Elizabeth	39	8	1356	470	0.644	0.727	0.828	0.937	1.049
48	Adams	21	14	1356	470	0.875	0.980	1.115	1.279	1.451

crashes is mildly significant, but Merrill Plaisance with 18 before crashes and four after crashes is not. The 75th percentiles for these two intersections are 0.998 and 1.006, respectively. Other intersections, such as Manchester or Adelaide, are also borderline significant as their percentile values are close to 1.

Since the intersections are ordered from northwest to southeast, boxplots are useful as a graphical tool for detecting spatial patterns in the intersections. Boxplots might show significant intersections that group together. Figure 9 and Figure 10 show boxplots of distributions for the parameter of interest and their relations with respect to the null value 1. Even though only intersection 3 is strongly significant, there is a clear trend that the majority of the boxes are less than 1. There does not appear to be a large spatial component where certain intersections group together, but there is not a lot of variability among the boxplots. Note that intersections 19 (Cortland) and 48 (Adams) almost attain mild significance in increased numbers of crashes, but not quite.

Figure 9. Boxplots of Intersections on Woodward Avenue (first 24 plots)

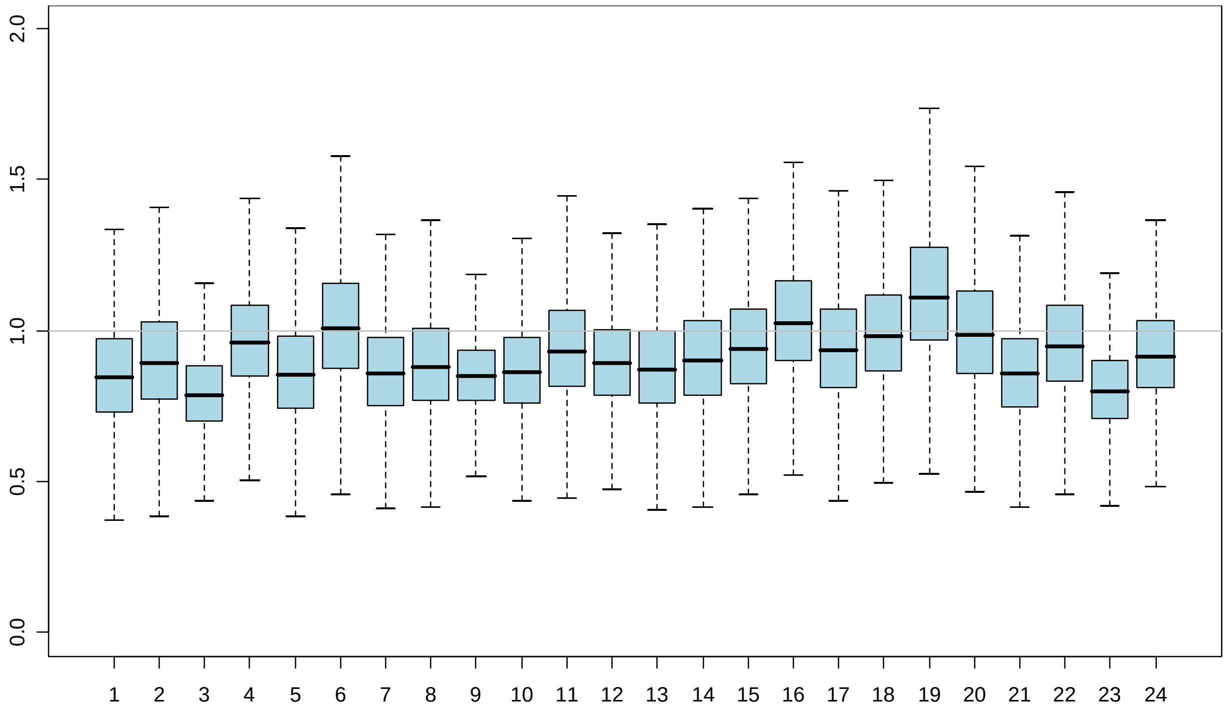


Figure 10. Boxplots of Intersections on Woodward Avenue (second 24 plots)

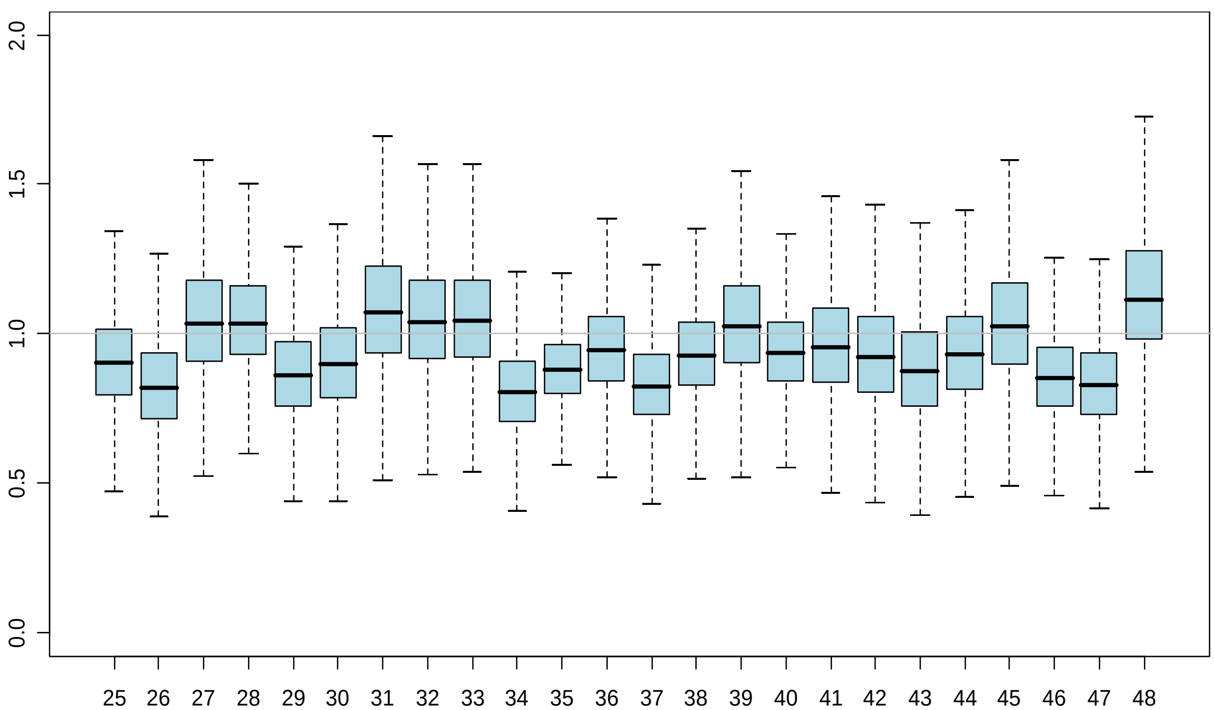


Table 15 shows summary statistics for injury severity, time of day, day of week, and crash type for Woodward as a whole. The percentage of property-damage-only crashes is consistent with other corridors, about 78 percent. The percentage of rear-end crashes on Woodward Avenue is lower than on the other four corridors. The percentage of rear-end crashes is about 30 percent, the percentage of sideswipe crashes is about 24 percent, and the percentage of angle crashes is about 22 percent. As on other corridors, most crashes occur in the daytime, but about 22 percent occur between 8:00 p.m. and 5:59 a.m. Crashes are distributed fairly evenly by day of week, with slightly elevated numbers on Fridays and slightly reduced numbers on Sundays. It does not appear that the distributions of any of these four variables changed significantly after signal timing.

On Woodward Avenue, there were 1,676 crashes before signal timing and 524 after. As shown in Tables 13 and 14, the number of before days is 1,356 and the number of after days is 470. The Z-statistic, calculated from these numbers using the formula shown in Appendix C, gives Z = 2.06. Since Z is greater than 1.96, it is concluded that the number of crashes on Woodward was reduced significantly after signal timing overall. Note that 2.06 is very close to 1.96, so among the corridors that attain significance using the Z-statistic, the result on Woodward is the weakest.

Table 15. Summary Statistics for Woodward Avenue

Injury Severity	Before	%	After	%
Fatal	6	0.4	1	0.2
A-Injury	45	2.7	14	2.7
B-Injury	77	4.6	18	3.4
C-Injury	236	14.1	83	15.8
O-Injury	1,312	78.3	408	77.9
Total	1,676	100.0	524	100.0

Time of Day	Before	%	After	%
6:00 a.m. - 9:59 a.m.	207	12.4	80	15.3
10:00 a.m. - 3:59 p.m	589	35.1	205	39.1
4:00 p.m. - 7:59 p.m.	418	24.9	126	24.0
8:00 pm - 5:59 a.m.	366	21.8	102	19.5
Unknown	96	5.7	11	2.1
Total	1,676	100.0	524	100.0

Day of Week	Before	%	After	%
Sunday	186	11.1	43	8.2
Monday	236	14.1	73	13.9
Tuesday	232	13.8	83	15.8
Wednesday	258	15.4	91	17.4
Thursday	252	15.0	73	13.9
Friday	306	18.3	91	17.4
Saturday	206	12.3	70	13.4
Total	1,676	100.0	524	100.0

Crash Type	Before	%	After	%
Single vehicle	90	5.4	34	6.5
Head-on	103	6.1	40	7.6
Angle	355	21.2	128	24.4
Rear-end	531	31.7	153	29.2
Sideswipe	409	24.4	121	23.1
Other/unknown	188	11.2	48	9.2
Total	1,676	100.0	524	100.0

9. Crash Type and Crash Severity

In this section the association between the signal optimization treatment and two outcome variables, crash type and crash severity, is considered.

Crash types were aggregated to form simpler categories, categories that grouped the crashes by the direction of motion of the vehicles prior to the crash. This simplification is necessary to support sample sizes large enough to achieve statistical and practical significance. The categories were single-vehicle crashes, involving only one motor vehicle, though note that crashes with bicyclists and pedestrians would be included in this group; opposite-direction crashes, in which the vehicles were traveling in opposing directions prior to the crash; same-direction crashes, in which both vehicles were traveling along the same road in the same direction; and angle crashes, in which the direction of travel was perpendicular or nearly so. Sideswipes were included in the appropriate category, based on intended travel direction. This method of categorization groups opposite-direction sideswipes with head-on collisions, and same-direction sideswipes with rear-end crashes. This is a reasonable grouping, particularly in the case of intersection crashes. Sideswipes are often the result of an avoidance maneuver that was almost successful after a conflict was perceived by the driver. The driver sees a conflict ahead, maneuvers to avoid, and sideswipes the vehicle rather than squarely rear-ending it. Same-direction sideswipes also occur in lane-change crashes, but lane-change maneuvers are less likely at an intersection. By including sideswipes in the appropriate directional category, we capture the fundamental travel vectors of the vehicles prior to the collision.

Table 16 compares the distribution of crash type for intersections found to have a significant reduction in the number of crashes after signal optimization. The table includes all crashes, both before and after the treatment, so it does not reflect the effect of signal optimization. Or rather, any effects of signal optimization are included in the table. The intersections that did not show a significant decline in the number of crashes had a somewhat different distribution of crash types from intersections in which signal optimization did reduce crashes. The “no change” intersections had a higher proportion of same-direction collisions and lower proportions of angle and opposite-direction crashes, primarily angle. The differences in proportion for the specific crash types mentioned were statistically significant.

Table 16. Crash Type by Intersection Treatment Outcome

	No Change		Significant Reduction	
Crash Type	N	%	N	%
Single vehicle	361	3.6	81	3.7
Opposite direction	815	8.1	201	9.2
Same direction	6,441	63.8	1,303	59.7
Angle	2,090	20.7	521	23.9
Other/Unknown	391	3.9	78	3.6
Total	10,098	100.0	2,184	100.0

Though relatively minor, it does appear that the intersections that showed no significant effect of the signal optimization are associated more with rear-end crashes, which might be related to high volumes of traffic and frequent stops or slowing. The intersections that did show a reduction in the number of crashes had more conflicts from crossing traffic, and thus more angle collisions. The difference in the proportion of opposite-direction crashes was not significant, statistically or otherwise.

The next two tables disaggregate the data in Table 16 into crashes occurring prior to optimization and those that occurred after optimization. Splitting the data this way more clearly shows that the differences in the distribution of crash types was not related to the optimization but reflects other factors associated with the intersections. Table 17 shows the distribution of crash types before optimization for intersections that showed an effect and those that did not. Intersections that showed a significant reduction had a higher proportion of angle crashes and a lower proportion of same-direction collisions. Both differences are statistically significant.

Table 17. Crash Type Distribution Before Signal Optimization by Intersection Treatment Outcome

	No Change		Significant Reduction	
Crash Type	N	%	N	%
Single vehicle	248	3.7	54	3.3
Opposite direction	542	8.0	154	9.5
Same direction	4,284	63.6	965	59.4
Angle	1,381	20.5	384	23.6
Other/Unknown	284	4.2	67	4.1
Total	6,739	100.0	1,624	100.0

Table 18 shows that the differences between the intersections (helped and not helped) remained after optimization, although this time the differences just fall short of statistical significance at the 0.05 level. However, the results for same-direction and angle collisions are the same magnitude as those observed in Table 17.

Table 18. Crash Type Distribution After Signal Optimization by Intersection Treatment Outcome

	No Change		Significant Reduction	
Crash Type	N	%	N	%
Single vehicle	113	3.4	27	4.8
Opposite direction	273	8.1	47	8.4
Same direction	2,157	64.2	338	60.4
Angle	709	21.1	137	24.5
Other/Unknown	107	3.2	11	2.0
Total	3,359	100.0	560	100.0

Since there appeared to be differences between the intersections that showed a reduced number of crashes and those that did not after the signal optimization, it was hypothesized that the signal optimization itself may have changed the distribution of crashes. For example, the optimized signals may have increased traffic flow through the intersection and reduced the number of rear-end crashes. However, it appears that the effect of optimization was to reduce all crash types relatively equally. Table 19 shows that the distribution of crashes did not change between the before and after period. None of the differences are statistically significant and all are too small to have practical significance.

Table 19. Crash Type Before and After Signal Optimization
Intersections Showing Significant Reduction Only

	Before		After	
Crash Type	N	%	N	%
Single vehicle	54	3.3	27	4.8
Opposite direction	154	9.5	47	8.4
Same direction	965	59.4	338	60.4
Angle	384	23.6	137	24.5
Other/Unknown	67	4.1	11	2.0
Total	1,624	100.0	560	100.0

There also was no detectable effect from signal optimization on the severity of crashes that occurred at the intersections. Table 20 tabulates the distribution of crash severity for intersections that showed a significant reduction in crashes after signal optimization and those that did not. The table shows all crashes, regardless of whether they occurred prior to or after optimization. There is no practical difference between the two distributions. It does not appear that the two groups of intersections differed in the severity of crashes. Overwhelmingly, the crashes were relatively minor. About 80 percent included no injury at all and another roughly 15 percent included only a C-injury, which is complaint of pain but no evident injury. Thus, about 95 percent of the collisions involved little or no injury.

Table 20. Crash Severity by Intersection Treatment Outcome

	No Change		Significant Reduction		Total	
Crash Severity	N	%	N	%	N	%
Fatal	12	0.1	1	0.0	13	0.1
A-injury	156	1.5	26	1.2	182	1.5
B-injury	377	3.7	76	3.4	453	3.6
C-injury	1,603	15.7	331	14.9	1,934	15.5
No injury	8,073	79.0	1,783	80.4	9,856	79.2
Total	10,221	100.0	2,217	100.0	12,438	100.0

Similarly, signal optimization had no effect on the distribution of crash severity in the intersections that showed a reduction in the number of crashes. Table 21 shows the distribution of crashes in the before and after periods. Effectively, there is no practical difference in the two distributions. In the before period, about 4.5 percent of the crashes included a serious injury, either a fatal (zero), A-injury, or B-injury. In the after period, the percentage was 5.0 percent, a difference too small to be significant. Just as the effect of optimization appears to have reduced all crash types equally (see Table 19 above), optimization also appears to have reduced crashes of all severities more or less equally.

Table 21. Crash Severity Before and After Optimization
Intersections Showing Significant Reduction Only

	Before		After	
Crash Severity	N	%	N	%
Fatal	0	0.0	1	0.2
A-injury	19	1.1	7	1.2
B-injury	56	3.4	20	3.6
C-injury	246	14.9	85	15.1
No injury	1,334	80.6	449	79.9
Total	1,655	100.0	562	100.0

10. Discussion about Average Daily Traffic (ADT) Counts

Since this is a before-after study of signal timing at intersections, it is important to account not only for the numbers of crashes before and after the intervention, but also for changes in exposure. The statistical model used in this study accounts for the different numbers of days during the before and after periods. For example, on Ford Road and Plymouth Road, the number of days during the before periods is 1,217 days, while the number of days during the after periods is 609 days. On these two corridors, the time exposure is approximately twice as long during the before periods. The model accounts for these differences.

Another kind of exposure is average daily traffic (ADT) counts. It would be important to adjust for differences in ADT relative to the before period if this measure either increased or decreased during the after period. For example, if the numbers of crashes increases significantly during the after period on a corridor, it may be due to increases in traffic volume or population density. Such an increase in crashes would at least be partially, if not mostly, attributable to the increase in traffic volume or ADT, and not wholly attributable to the signal timing intervention. Any analysis should account for changes in traffic volume or ADT if they occurred.

In Section 3.1, it was shown that the estimated change in population from April 2000 to July 2006 decreased by 3.6 percent in Wayne County, while the estimated change in population during the same period in Macomb County increased by 6.2 percent. It was also shown in Section 7 that in general, numbers of crashes increased on Hall Road (M-59), which is located in Macomb County, after signal timing. For the 28 intersections on this corridor, numbers of crashes increased significantly on seven intersections, while the number of crashes was reduced significantly on only one intersection. Since Macomb County grew in population relative to the before and after periods of this study, the increase in crashes after signal timing observed on Hall Road could be influenced by increased traffic volume.

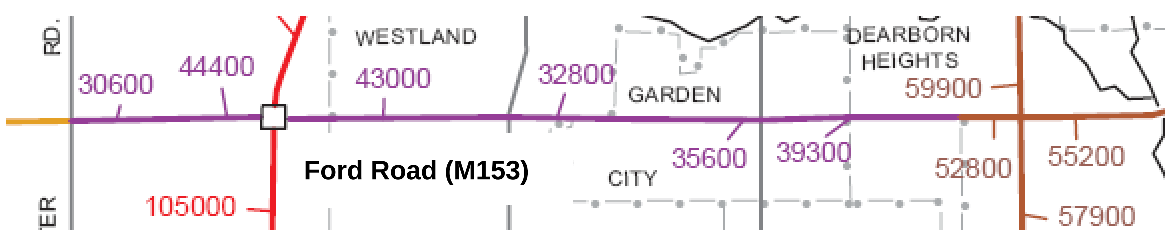
ADT counts recorded by the Michigan Department of Transportation (MDOT) provide some information to assess the change of traffic volume before and after signal timing on the corridors under investigation[2]. The ADT counts are measured at locations located along each corridor, and generally not at the specific intersections considered in this study. However, yearly counts are available along the corridors, and the intention is to determine if any yearly trends can be detected in traffic volumes between 2002 and 2005.

Table 22 shows estimated ADT at specific locations located along the Ford Road corridor. The ADT counts are available at eight locations in the approximate vicinity of the 26 intersections investigated on this corridor. From the before period to the after period, the total ADT decreased from 332,871 to 323,520 or by approximately 2.81 percent. At one specific location, ADT decreased by as much as 10.13 percent, while at another it increased by 5.96 percent. Figure 11 shows the source of ADT counts on Ford Road for 2002.

Table 22. Estimated Average Daily Traffic (ADT) and Percentage Change on Ford Road

	Canton	West of I275	East of I275	Wayne	West of Middlebelt	East of Middlebelt	West of Telegraph	East of Telegraph	Total
2002	30,600	44,400	43,000	32,800	35,600	39,300	52,800	55,200	333,700
2003	30,600	44,400	43,000	32,800	35,600	39,300	52,800	55,200	333,700
2004	30,400	40,300	41,900	30,400	35,800	33,700	53,000	62,400	327,900
2005	28,400	39,600	44,500	29,800	33,400	35,200	52,000	57,700	320,600
Before	30,571	43,814	42,843	32,457	35,629	38,500	52,829	56,229	332,871
After	29,200	39,880	43,460	30,040	34,360	34,600	52,400	59,580	323,520
% Chg	-4.49	-8.98	1.44	-7.45	-3.56	-10.13	-0.81	5.96	-2.81

Figure 11. Average Daily Traffic Counts on Ford Road 2002 (MDOT)



[2] Average daily traffic (ADT) is not available for 2001, is not available in some cases in 2005, and is not available for Plymouth Road. Since signal timing occurred in 2004, the before and after counts presented in Tables 23 through 25 are calculated by allocating the 2004 ADT to the before and after periods according to the month of signal optimization in 2004.

Table 23 shows ADT measurements taken at three locations in and around the Jefferson corridor between 2002 and 2004. Note that estimated ADT for 2005 is not available. This corridor is very short, measuring approximately one-third of a mile. One measurement, Jefferson, appears to be at the center of the corridor. Two other measurements, labeled Vicinity 1 and Vicinity 2, are in close proximity to the Jefferson corridor. Based on the information in Table 23, it appears that the ADT on this corridor did not change greatly, even though it appears to have increased slightly by 1.49 percent. In Section 6 it was estimated that of all the corridors, Jefferson showed the greatest reduction in crashes after signal timing. Changes in ADT do not appear to affect that result.

Table 23. Estimated Average Daily Traffic (ADT) and Percentage Change on Jefferson Avenue

	Jefferson	Vicinity 1	Vicinity 2	Total
2002	48,500	36,200	14,000	98,700
2003	48,900	36,400	15,500	100,800
2004	49,100	36,600	15,600	101,300
2005	NA	NA	NA	NA
Before	48,716	36,312	14,784	99,812
After	49,100	36,600	15,600	101,300
% Chg	0.79	0.79	5.52	1.49

Table 24 shows the estimated ADT at five locations located along Hall Road. Of all the corridors, this is the one for which ADT is of most interest because in Section 7 it was estimated that this corridor showed a general increase in crashes after signal timing. Since Macomb County also showed a 6.2 percent increase in population between 2000 and 2006, one might hypothesize that the observed increase in crashes on Hall Road might be attributable to increased traffic volume. If the estimates in Table 24 are judged to be accurate, the hypothesis does not appear to be supported. The overall increase in traffic volume is only about 1 percent, and individual increases or decreases at the five locations are not large enough to alter the results.

Table 24. Estimated Average Daily Traffic (ADT) and Percentage Change on Hall Road

	Utica	West of M53	East of M53	Hayes	Card	Total
2002	78,900	82,700	92,000	79,600	66,700	399,900
2003	78,900	87,400	92,000	79,600	66,700	404,600
2004	82,100	87,800	86,900	85,000	70,100	411,900
2005	81,800	82,500	86,500	84,600	69,800	405,200
Before	79,405	85,484	91,195	80,453	67,237	403,774
After	81,915	84,538	86,654	84,754	69,915	407,777
% Chg	3.16	-1.11	-4.98	5.35	3.98	0.99

Table 25 shows the estimated ADT results for Woodward Avenue. Note that estimates for 2005 are not available. The overall estimated ADT counts at the approximate five locations shown in Table 25 are 118,488 before the signal timing treatment and 119,300 after treatment. This represents an increase of only 0.69 percent, or practically no change. The individual changes at the five locations are not large enough to significantly affect results presented in earlier sections.

Table 25. Estimated Average Daily Traffic (ADT) and Percentage Change on Woodward Avenue

	7 Mile	6 Mile	Highland Park	Tennyson	Warren	Total
2002	23,800	23,800	27,600	21,400	21,200	117,800
2003	24,000	24,000	27,800	21,500	21,300	118,600
2004	24,100	24,100	26,500	21,100	23,500	119,300
2005	NA	NA	NA	NA	NA	NA
Before	23,952	23,952	27,386	21,358	21,838	118,488
After	24,100	24,100	26,500	21,100	23,500	119,300
% Chg	0.62	0.62	-3.24	-1.21	7.61	0.69

Although ADT is not available at the level required to adjust significance of results for each intersection individually, traffic volumes are recorded at certain locations along all corridors, except Plymouth Road, and for most of the years covering the data used in this study. Traffic volumes are not available in 2001. However, based on available ADT as presented in this section, it does not appear that adjustment of crash counts by ADT exposure would *significantly* alter the findings presented in Sections 4 through 8. This conclusion is particularly relevant with respect to Hall Road (M-59) because, in general, numbers of crashes on this corridor increased after signal timing.

11. Summary and Discussion

The effects of a signal timing intervention were evaluated for 130 intersections located on five corridors in southeast Michigan. Effects were evaluated based on changes in the numbers of crashes after signal timing. Michigan crash data were collected for five years including 2001 through 2005, and numbers of crashes were counted both before and after signal timing. Crashes were geographically located on maps, and summary statistics were calculated for injury severity, time of day, day of week, and crash type for each intersection.

A statistical model in the Bayesian framework was developed to determine if numbers of crashes increased or decreased at each of the 130 intersections. The modeling procedure is especially suited to handle small numbers of crashes and contains effects for intersections, corridors, before and after crashes, and before and after days of signal timing. The model has one parameter for each intersection that is used to assess significance after signal timing. If this parameter is significantly greater than 1, it was concluded that the number of crashes was increased after signal timing. If the parameter was significantly less than 1, it was concluded that the number of crashes was reduced. Boxplots were shown that graphically display the results for each intersection.

Table 26 shows a ranking of the corridors in terms of numbers of reduced crashes overall. The table shows the number of intersections that attain strong decreases, mild decreases, no change, mild increases, and strong increases in the number of crashes after signal timing. Although the ten intersections on Jefferson Avenue are in close proximity and span approximately one-third

Table 26. Ranking of Corridors by Strength of Crash Reduction after Signal Timing

Corridor	Strong decrease	%	Mild decrease	%	No change	%	Mild increase	%	Strong increase	%	Total
Jefferson	7	70.0	2	20.0	1	10.0	0	0.0	0	0.0	10
Plymouth	3	16.7	7	38.9	7	38.9	0	0.0	1	5.6	18
Woodward	1	2.1	15	31.3	32	66.7	0	0.0	0	0.0	48
Ford Road	4	15.4	2	7.7	15	57.7	2	7.7	3	11.5	26
Hall Road	1	3.6	0	0.0	16	57.1	4	14.3	7	25.0	28
Total	16	12.3	26	20.0	71	54.6	6	4.6	11	8.5	130

of a mile, this corridor shows the strongest decrease in the number of crashes of the five corridors studied. Seven of the intersections show strong reductions, two intersections show mild reductions, and one intersection shows no change. No intersections on Jefferson Avenue show an increase in crashes, either mildly or strongly. Of the eighteen intersections on Plymouth Road, three show a strong decrease in crashes after signal timing, seven show a mild decrease, seven show no change, and one shows a strong increase. Thus, ten of the eighteen intersections, or 55.6 percent, show a strong or mild reduction in crashes after signal timing.

On Woodward Avenue, 32 of 48, or 66.7 percent, of intersections show no change in crashes after treatment. In addition, no intersections show an increase in crashes, either mildly or strongly. On the other hand, one intersection show a strong decrease and 15 intersections show a mild decrease, making Woodward a corridor that displays an overall trend of crash reduction, but a weaker trend than that displayed by either Jefferson Avenue or Plymouth Road.

On Ford Road, four intersections show a strong decrease in crashes after signal timing, but three intersections show a strong increase. Furthermore, two intersections show a mild decrease in crashes, but two intersections show a mild increase. The remaining 15 intersections on Ford Road show no change. While some intersections show decreases in crashes after signal timing, others show increases and the effects tend to balance. As a corridor, Ford Road does not show a significant change in numbers of crashes after signal timing overall.

Finally, of 28 intersections on Hall Road, only one shows a significant decrease in crashes after signal timing. Seven show significant increases in crashes, and four display mild increases. The remaining 16 show no change after treatment. Therefore, 11 of 28, or 39.3 percent, of the intersections on Hall Road show either a strong or mild increase in crashes. This is the only corridor of the five that shows an overall increase after signal timing. A simple hypothesis for this increase is that economic and community development in this region resulted in increased traffic volumes during the after treatment period. However, available average daily traffic (ADT) counts on Hall Road do not support this hypothesis. In relation to the before period, estimated ADT increased by approximately 1 percent during the after period.

Appendix A: Analytical Methodology

Bayesian Hierarchical Models for Assessing Numbers of Crashes at Signalized Intersections in a Before-After Study

Introduction

In this study, Bayesian data analysis was used to compare numbers of crashes at signalized intersections to determine if the numbers of crashes either decreased or increased after the signal timing intervention. Bayesian data analysis is useful for several reasons. First, when the numbers of crashes at certain intersections are small, the method incorporates prior information provided by other similar intersections with more crashes to aid in estimation. Therefore, estimation in the case of small sample sizes is facilitated by borrowing strength from intersections with large sample sizes. Second, since Bayesian data analysis is developed under the framework of a full probability model, estimation of uncertainty, as in the cases of hypothesis testing or calculation of confidence intervals, is generally more precise than the classical approach which is often based on large sample theory.

A full Bayesian hierarchical model with likelihood and proper prior distributions is outlined for assessing numbers of crashes before and after signal timing. A formal statistical test is proposed for whether numbers of crashes increased or decreased. The model applies to counts as well as rates, assuming that appropriate measures of exposure are available. The model incorporates a logit model in the prior specification for smoothing proportions, and scale parameters are included to accommodate uncertainty among the various intersections.

In the Bayesian framework, a likelihood and a prior distribution for model parameters are specified. Conditional on observing the data, the prior distribution is updated and inference about model parameters is made by calculating a posterior distribution. Since calculating posterior distributions is often difficult, Markov chain Monte Carlo (MCMC) simulations can be run to simulate random variables directly from posterior distributions. Using the output from MCMC, characteristics of a posterior distribution such as the mean, the standard deviation, and percentiles can be calculated.

The Likelihood

The Bayesian framework begins by specifying a likelihood for the observed data. Rare counts, such as crashes, are often modeled using the Poisson distribution. In the following setup, crashes at intersections are assigned Poisson distributions:

$$Y_b \sim \text{Poisson}(t_b\, \lambda) \qquad\qquad Y_a \sim Poisson(t_a\, \theta\, \lambda)$$

where Y_b represents the number of crashes at an intersection before the intervention, Y_a represents the number of crashes at the same intersection after the intervention, t_b and t_a are exposures before and after signal timing such as number of days or average annual daily traffic (AADT), respectively, λ is an expected rate, and θ is the parameter of interest in the hypothesis

$$H_0 : \theta = 1$$
$$H_1 : \theta \neq 1.$$

If $\theta = 1$, then the expected rates for crashes before and after signal timing were the same, and equal to λ. If H_0 is rejected, then the expected rate before the intervention is λ, but the expected rate after the intervention is $\theta\lambda$. Note that this setup conveniently accommodates the analysis of counts or rates. When modeling counts, the exposures are set to 1 ($t_b = t_a = 1$) and λ is the expected count.

Since interest focuses on θ, and not λ, λ can be treated as a nuisance parameter. One way to eliminate λ from this analysis is to condition on the sum $Y_b + Y_a$. As shown and used by Farewell and Sprott [7], the distribution of the number of crashes, conditioned on the fixed sum is Binomial,

$$Y_b \mid Y_b + Y_a = T \sim Binomial(T, p)$$

where $p = t_b /(t_b + t_a\,\theta)$. Note that this likelihood depends only on the unknown θ and not λ.

The Prior Distribution

Large sample results based on normal theory are available for testing H_0 using the above result, however, crash counts at intersections may be small, and so the next step of the modeling framework is to specify a prior distribution on θ. Updating the prior with the data will lead to calculation of a posterior distribution for θ, giving an estimate that is a weighted average of the data and the prior. In the posterior distribution, when the number of crashes at an intersection is large, the data will provide a good estimate of θ. When the sample size is small, the estimate of θ will be smoothed towards the prior. Thus, the prior will incorporate information about explanatory variables particular to an intersection and corridor in a regression model. Suppose numbers of crashes are recorded at N intersections before and after signal timing along with exposure measures for each. The model

$$\text{logit}(p_i) = \log\left(\frac{p_i}{1-p_i}\right) = X_i^T\beta + \varepsilon_i \qquad i = 1, 2, \cdots\cdots, N$$

describes a logit model relating θ_i (through p_i) to a p-dimensional row vector of explanatory variables $X_i^T = (X_{i1}, \cdots, X_{ip})$ and a p-dimensional column vector of unknown parameters $\beta = (\beta_1, \cdots \beta_p)^T$. The ε_i are modeled as independent normal random variables with mean 0, and variance σ^2. The hyperparameter σ^2 is a scale parameter that allows for extra variability beyond that accommodated by binomial sampling and helps to adjust estimated standard errors of model parameters.

To complete the Bayesian setup in the context of a full probability model, at the second prior and final stage of the hierarchical model, the hyperparameters β and σ^2 are assigned noninformative, but proper priors. This ensures propriety of all posterior distributions. For example, β is assigned a relatively flat normal distribution and $1/\sigma^2$ is assigned a gamma distribution

$$\beta \sim N(0,10^6) \qquad 1/\sigma^2 \sim \text{Gamma}(0.5,0.0005)\,.$$

In this specification, β is relatively flat over the real line due to the large variance, and the expected value and variance of $1/\sigma^2$ are 1,000 and $2x10^6$, respectively.

Estimation

Direct calculation of posterior distributions based on the model described above is intractable. However, a Markov chain can be run to simulate random variables from the posterior distributions of each θ. Since the Markov chain converges to the desired posterior distributions, initial simulations are discarded. After running a Markov chain for 20,000 iterations and discarding the initial 5,000 to ensure that the chain has converged, the boxplots below show examples of posterior distributions of θ for the 26 intersections located on Ford Road in this study. If the middle, say 90 percent, of a distribution covers the null value of 1, then it is concluded that no statistical difference exists in the numbers of crashes before and after implementation of signal timing.

Kernel density plots are available for each θ. The plot below shows the density plot for intersection 16 (Middlebelt on Ford Road) and shows that the null value 1 lies in the upper right tail of the distribution. Any desired statistics can be generated from the output of the chain. Below are the mean, standard deviation, and the 10^{th}, 50^{th}, and 90^{th} percentiles. The 90^{th} percentile is less than 1.

Finally, below is the output (index plot) for 15,000 iterations of the Markov chain which simulates random variables from the posterior distribution of θ_{16}. All output shown below is generated from these kinds of simulations.

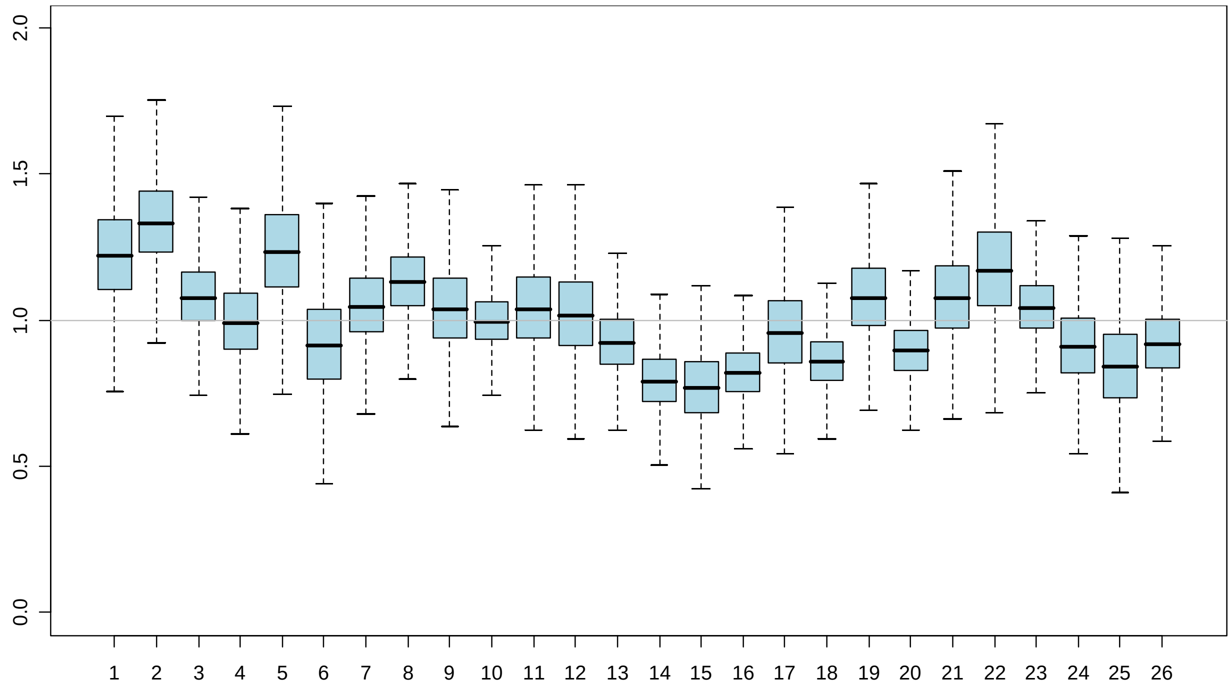


Figure 12. Boxplots of Posterior Distributions for Intersections on Ford Road

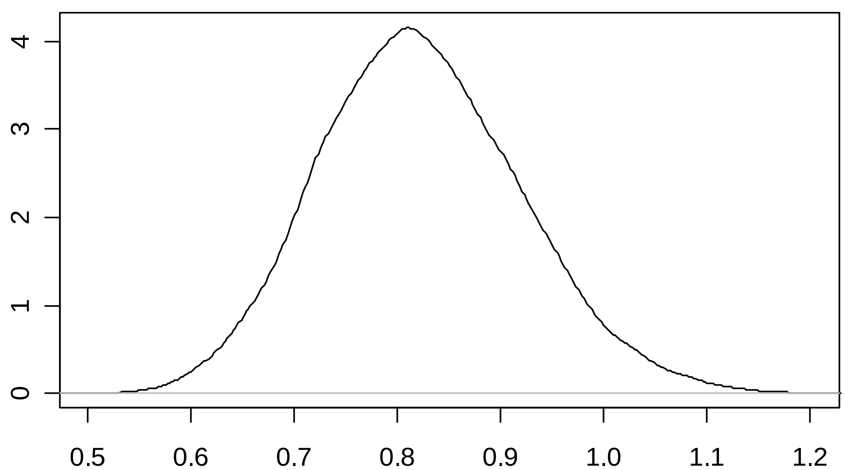


Figure 13. Density Plot for Posterior Distribution of Intersection 16 (Middlebelt)

Parameter	Mean	sd	10%	50%	90%
theta[16]	0.823	0.098	0.701	0.818	0.951

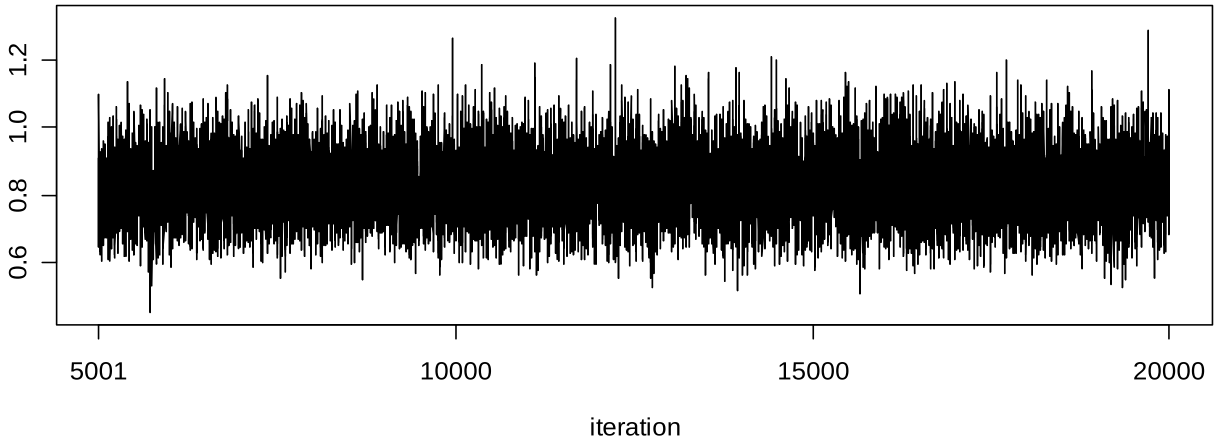


Figure 14. Index Plot of 15,000 Iterations of the Markov Chain (Middlebelt)

Appendix B: Descriptive Measures for Each Intersection

Appendix B is contained in a separate volume. It contains maps of crashes geographically located both before and after signal timing for all 130 intersections on five corridors under investigation in this study. The intersections are grouped according to corridor.

Appendix C: Large Sample Test for Overall Significance on a Corridor

In Appendix A, a Bayesian modeling procedure was described for assessing significance of intersection crashes after signal timing. One of the advantages of that procedure is its usefulness for estimation when sample sizes are small. The model borrows information from intersections with large numbers of crashes to aid in estimation at intersections with small numbers of crashes. However, for all crashes on a corridor, the number of crashes is expected to be large. For example, Table 4 shows that the number of before crashes was 2,801 and the number of after crashes was 1,410. These numbers are in the thousands, and a large sample result can be used to determine if the number of crashes changed significantly after signal timing.

Following the notation in Appendix A, crashes at intersections are assigned Poisson distributions

$$Y_b \sim \text{Poisson}(t_b\,\lambda) \qquad\qquad Y_a \sim Poisson(t_a\,\theta\,\lambda)$$

where Y_b represents the number of crashes at an intersection before the intervention, Y_a represents the number of crashes at the same intersection after the intervention, t_b and t_a are exposures before and after signal timing such as number of days or average annual daily traffic (AADT), respectively, λ is an expected rate, and θ is the parameter of interest in the hypothesis

$$H_0 : \theta = 1$$
$$H_1 : \theta \neq 1.$$

The test statistic for testing H_0 is

$$Z = \frac{\hat{p} - p_0}{\sqrt{\frac{p_0(1-p_0)}{n}}}$$

where $\hat{p} = \frac{Y_b}{Y_b + Y_a}$ $\qquad p_0 = \frac{t_b}{t_b + t_a}$ $\qquad n = Y_b + Y_a$.

For example, for all crashes on Ford Road, $Y_b = 2801$, $Y_a = 1410$, $t_b = 1217$, and $t_a = 609$. Direct calculation gives Z = -0.18. Since Z has an asymptotic standard normal distribution when H_0 is true, the decision rule is to reject H_0 if Z>1.96 or if Z<-1.96. Since Z=-0.18, we fail to reject H_0 and conclude that there is no difference in the overall number of crashes on Ford Road after signal timing. If Z>1.96 it is concluded that the number of crashes reduced significantly after signal timing. If Z<-1.96 it is concluded that the number of crashes increased significantly.

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