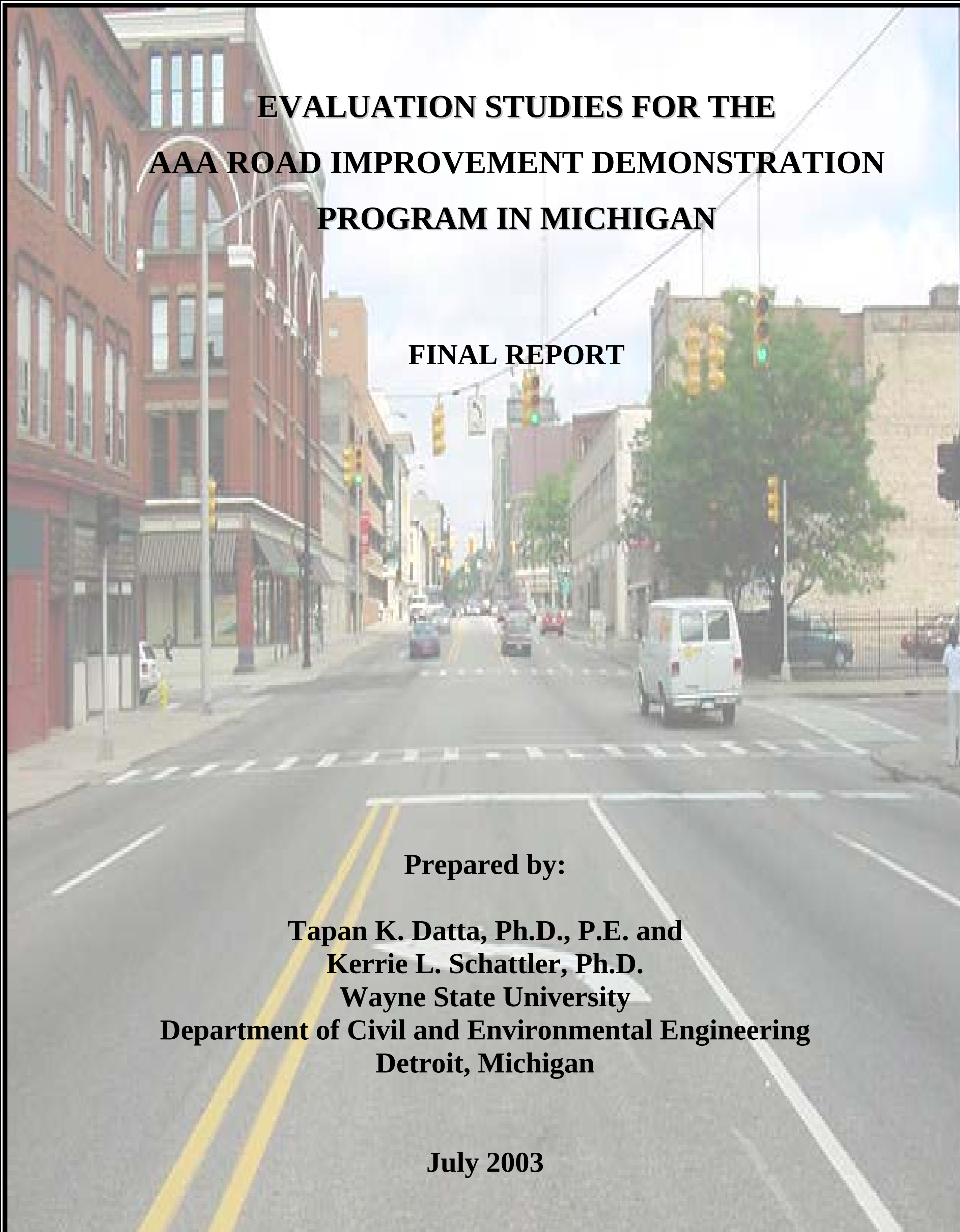

EVALUATION STUDIES FOR THE AAA ROAD IMPROVEMENT DEMONSTRATION PROGRAM IN MICHIGAN

FINAL REPORT

Prepared by:

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EXECUTIVE SUMMARY

INTRODUCTION

In 1996, the Automobile Association of America (AAA), Automobile Club of Michigan initiated the Road Improvement Demonstration Program (RIDP) involving a public-private partnership to identify high crash locations, and to develop and implement safety measures in the Cities of Detroit and Grand Rapids. The public private venture in Detroit originally included the City of Detroit and the Automobile Club of Michigan. Later the Southeast Michigan Council of Governments (SEMCOG), Wayne County, the Michigan Office of Highway Safety Planning (MOHSP) and the Michigan Department of Transportation (MDOT) became involved. Similarly, the public-private partnership in Grand Rapids was established and includes the City of Grand Rapids, the Automobile Club of Michigan and MDOT.

The RIDP was designed to enhance traffic safety by reducing the frequency and severity of crashes at high-risk urban intersections. Over the past seven years, the Automobile Club of Michigan has initiated the study of 300 intersections in Detroit and Grand Rapids, out of which safety improvements have been implemented at 172 sites to date.

The Wayne State University-Transportation Research Group (WSU-TRG) received funding to perform a continuing effectiveness evaluation of the RIDP from MOHSP and the Automobile Club of Michigan. Eighty-five (85) signalized intersections located along six major corridors and at isolated intersections are the focus of this evaluation report. The 85 test intersections from this program were selected based on their improvement completion dates. This evaluation study can be considered as representative of the total Road Improvement Demonstration Program.

Seventy-two (72) of the 85 study intersections are located on corridor segments along Woodward Avenue, Grand River Avenue and Wyoming Road in Detroit, and Burton Street, Eastern Avenue and Division Avenue in Grand Rapids. In addition, a total of 13 isolated intersections were also studied.

STUDY OBJECTIVES

The objectives of this evaluation study are as follows:

- To determine the effectiveness of the safety improvements using a 'before and after' experimental plan at the corridors and intersections in the cities of Detroit and Grand Rapids
- To determine the effectiveness of the safety improvements at selected intersections through the use of control site experiments
- To determine the effectiveness of specific countermeasures and combination of safety treatments in alleviating traffic crash and injury problems
- To perform an economic analysis of the implemented safety treatments at the study intersections

SITE SELECTION AND IMPLEMENTED IMPROVEMENTS

The improvements implemented at the test intersections varied slightly from location to location, however in general the improvements were low cost.

The intersections and corridors included in the Michigan RIDP were initially selected for improvements based on their traffic crash experience and based on an analysis of insurance claims. It is important to note that the corridors had high crash experiences at some of the major intersections, while other intersections in the corridors experienced a low number of crashes. At the corridor level, most of the improvements were implemented at both the high and low crash intersections. The following are some of the countermeasures implemented at the intersections and corridors:

General Corridor Improvements:

- Implemented all-red intervals with lengths calculated as per the Institute of Transportation Engineer's (ITE) guidelines.
- Replaced all 8-inch signal lenses with 12-inch signal lenses, even though the speed limit on the roads does not exceed 40 miles per hour (mph).

- Relocated the signal heads to improve visibility.
- Installed secondary post mounted signal heads to improve visibility at some locations.
- Installed back plates on the traffic signals to improve visibility at some locations.
- Installed exclusive left-turn lanes and/or permissive/protected left-turn phases at some locations based on less conservative guidelines for the installation of left-turn phases than typically used in Michigan.
- Modified signal timings at all the study intersections based on current traffic volume data.

Isolated Intersection General Improvements:

- Repaved the intersection approaches.
- Installed exclusive left-turn lanes and/or permitted/prohibited left-turn phases, where needed.
- Replaced 8-inch signal lenses with 12-inch lenses, even if the speed limit did not exceed 40 mph.
- Modified signal timing based on current traffic volumes and provided all-red intervals with lengths calculated as per the ITE guidelines.
- Eliminated on-street parking in close proximity of the intersections.

DATA COLLECTION

The following data was collected to perform the evaluation study:

- Pre-implementation study reports were obtained and reviewed in order to establish the ‘before’ condition including intersection geometry, traffic volumes, traffic control characteristics, safety deficiencies, targeted crash types and crash severities, and proposed countermeasures
- Actual improvement plans for each of the intersections and corridors were obtained, if available, and reviewed.

- ‘Before’ and ‘after’ traffic crash data was obtained from the police traffic crash reports (UD-10 forms).
- 24-hour approach or midblock traffic counts were obtained from the respective city agencies in Detroit and Grand Rapids.

TRAFFIC CRASH ANALYSIS

Traffic crash data from the police traffic crash reports (UD-10 forms) were collected for the ‘before’ and ‘after’ implementation periods. Since the state of Michigan’s computerized database inherently contains errors related to crash type and crash location, crash data from the UD-10 police report forms were analyzed in order to determine accurate crash types and crash locations.

For the ‘before’ period, historic traffic crash data was collected for a two-year period for the majority of the intersections. Traffic crash data for the ‘after’ period was collected one month after the installation of the countermeasures and was continually collected on a monthly basis, as soon as the traffic crash reports became available. The ‘after’ crash data at the majority of the study locations ranged from one to four years of data. As a part of this evaluation study, the WSU-TRG engineers thoroughly analyzed each and every UD-10 crash report form in order to determine how and where the crash actually happened. This was done by examining the crash diagrams and remarks contained in the UD-10 forms, the direction of travel of the involved vehicles, and the intent of the drivers before the first impact. Thus, the crash analysis as performed in this study will provide an accurate assessment of the effectiveness of the implemented intersection treatments. The effectiveness evaluation was based on total crashes, injury crashes and targeted crash types, which include angle and left-turn head-on crashes.

The ‘before’ and ‘after’ crash frequencies by crash type for the study intersections and corridors are shown in Table ES-1.

Table ES-1. 'Before' and 'After' Crash Frequencies for the Michigan RIDP

	ANNUAL AVERAGE BEFORE AND AFTER CRASH FREQUENCIES							
	TOTAL		INJURY		ANGLE		LEFT-TURN HEAD-ON	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
Woodward Avenue Corridor	469.5	313.1	137.5	74.8	116.0	28.1	32.5	45.5
Grand River Avenue Corridor	144.5	136.5	37.5	47.0	19.5	22.2	11.0	9.2
Wyoming Road Corridor	176.2	103.1	47.7	21.1	43.8	21.1	21.5	5.2
Burt Street Corridor	199.0	132.4	54.0	30.5	30.0	11.3	42.5	17.8
Division Avenue Corridor	208.0	183.5	62.0	38.5	35.5	21.8	45.0	18.9
Eastern Avenue Corridor	151.4	101.0	42.3	16.8	41.5	11.6	24.6	11.3
Isolated Intersections	432.1	279.3	125.4	69.8	92.9	25.6	78.8	30.5
OVERALL RIDP	**1,780.7**	**1,248.9**	**506.4**	**298.5**	**379.2**	**141.7**	**255.9**	**138.4**

EXPERIMENTAL PLAN AND STATISTICAL ANALYSES

The evaluation plan consisted of 'before and after' (B&A) studies performed for all the test intersections and corridors, as well as 'before and after with control' studies and the Empirical Bayes method applied to a sample of intersections in Detroit and Grand Rapids.

Conceptually, the B&A study assumes the expected crash measures of effectiveness (MOE) for the 'after' period to be the same as the 'before' crashes for locations where no improvements are made. Therefore, the change in the crash MOEs is measured as the difference in the 'before', and 'after' crash MOEs. The percent reductions based on the B&A study are shown in Table ES-2 for the corridors and isolated intersection locations. The statistical significance of the reductions in crashes was determined using the Poisson Test, using a confidence interval of 95 percent.

Table ES-2. Percent Reductions Based on the B&A Study for the Michigan RIDP Intersections and Corridors

CORRIDORS/ INTERSECTIONS	PERCENT CRASH REDUCTIONS			
	TOTAL	INJURY	ANGLE	LEFT-TURN HEAD-ON
Woodward Avenue Corridor (33 signalized intersections)	33%	46%	76%	-40% (Increase) (Not targeted)
Grand River Avenue Corridor (8 signalized intersections)	6%	-26% (Increase)	-14% (Increase)	16%
Wyoming Road Corridor (5 signalized intersections)	41%	56%	52%	76%
Burton Street Corridor (8 signalized intersections)	33%	44%	62%	58%
Division Avenue Corridor (9 signalized intersections)	12%	38%	39%	58%
Eastern Avenue Corridor (9 signalized intersections)	33%	60%	72%	54%
Isolated Intersections (11 signalized intersections)	35%	44%	72%	61%
OVERALL RIDP	**30%**	**41%**	**63%**	**46%**

The results of this analysis indicated that the countermeasures installed were effective in reducing the targeted crash types. The following are the countermeasures, in general that were aimed at mitigating angle crashes:

- Installation of all-red intervals with lengths calculated as per the ITE guidelines.
- Relocation of the signal heads to improve visibility.
- Realignment of signal heads over travel lanes.
- Upgrading the signal heads to 12-inch diameters.
- Installation of back plates (Burton Street corridor, Grand Rapids).

For left-turn head-on crashes they are as follows:

- Installation of secondary post mounted left-turn signals.
- Installation of exclusive left-turn lanes and permissive/protected phases.

ADDITIONAL ANALYSES (Based on Selected Test Sites)

Analysis for the 'before and after with control' study and the Empirical Bayes method were conducted at a sample of eight test sites in the cities of Detroit and Grand Rapids. These additional analyses were performed for total crashes only.

The sample test intersections were considered candidate locations where regression to the mean effects are most likely to occur. They were selected where the test sites had annual average total crash frequency in the 'before' period of greater than 20 crashes per year. In addition, statistical analyses were performed at a corridor level in order to determine if the safety treatments were effective.

B&A with Control Studies

For the B&A with control analysis, the test intersections were paired with control intersections based on their similarity to the test intersections in terms of roadway geometry, traffic control and traffic volume. In order to perform the B&A with control study, the expected crash frequency of the test site if no improvements were made, was calculated. The expected frequencies of crashes without treatment was calculated in proportion to the change in crashes at the control site during the entire study period. Statistical tests were performed using the percent reductions based on the adjusted expected crash frequencies.

A set of statistical analyses were performed to determine the statistical significance of the total crash reductions based on the B&A with control studies. The results of the statistical tests performed, using the Poisson Test, the Chi-Square test and the Paired t-test, indicated that the results were similar irrespective of the type of tests performed.

Empirical Bayes Method

The Empirical Bayes (EB) method is based on the premise that traffic crashes at the test intersections are not the only measure used to assess their safety. Data related to other similar sites are used to determine the expected crash experience at a test site in the 'after' period, had the safety treatments not been installed, as well as other traffic parameters.

In order to perform this analysis, two regression models were developed, based on the traffic crash experience and traffic volume data at twenty-one similar sites located in the City of Grand Rapids and fifty-five intersections in the City of Detroit. The Grand Rapids model was used to test the effectiveness of Grand Rapids test sites and the Detroit model was used to test the Detroit test sites. The regression equations were used, along with the actual 'after' crash frequency at the test site, to calculate the expected number of crashes at the test site had the improvements not been installed. Percent reductions in total crashes were then calculated based on the EB method.

The EB method estimated a 56.11 percent reduction for the sample test intersections in the City of Detroit and 54.56 percent reduction for the sample test intersections in the City of Grand Rapids. In Detroit, the percent reduction using the EB method is essentially the same as the percent reduction obtained using the B&A study for the sample test intersections, and is higher than the results of the B&A with control study. In Grand Rapids, the percent reduction in total crashes using the EB method is higher than that obtained using both the B&A study and B&A with control study for the same sample test sites.

For the sample test intersections in both cities combined, an overall 55 percent reduction in crashes resulted from the EB method, a 45 percent reduction from the B&A with control study, and a 51 percent reduction was obtained from the B&A study.

Thus, the percent reductions based on the B&A study for the test sites in the City of Grand Rapids and the City of Detroit can be considered reasonably unbiased and represent true impact of the improvements.

Corridor Analysis

In addition, an analysis was performed to verify if the implemented safety treatments along the study corridors were effective at a corridor level, as well as at the individual test site. A methodology, based on a binomial distribution which considers the 'before' and 'after' crash frequencies as well as a factor to represent the crash experience for a large control area was applied to the study corridors in the cities of Detroit and Grand Rapids. The results of this statistical analysis indicated that the implemented safety treatments **were not only effective at a corridor level, but also consistently effective at all the individual test sites**. Therefore, the countermeasures, which include installing larger signal heads, all-red intervals, back plates, and others, on the whole tend to significantly reduce crash frequencies when properly installed.

CONCLUSIONS

The following is a summary of the findings and conclusions of this evaluation study.

1. In the AAA Michigan RIDP, the annual average total crash frequencies for the corridors and isolated intersections included in the evaluation study (85 intersections combined) were reduced by 30 percent, from 1,781 crashes per year in the 'before' period to 1,249 crashes per year in the 'after' period. Likewise, the injury crashes were reduced by 41 percent, from 506 crashes per year in the 'before' period to 299 crashes per year in the 'after' period.

2. This reduction in crashes demonstrates that the countermeasures implemented at the intersections and corridors in the cities of Detroit and Grand Rapids were effective in reducing the targeted crashes thereby, reducing the total number of crashes at these locations. The general countermeasures that were aimed at mitigating angle and injury crashes include the following:
   - Installing all-red intervals with lengths calculated as per the ITE guidelines.
   - Relocating signal heads to the center of the roadway or intended travel lanes to improve visibility.

- Replacing the 8-inch signal lenses with 12-inch signal lenses, in spite of the speed limit on the study roadways being lower than the recommended speed limit for installing 12-inch signal heads.
- Installing of back plates on the traffic signals to improve visibility and to reduce sun glare (Burton Street corridor, Grand Rapids).

The countermeasures for alleviating left-turn head-on and injury crashes included the following:

- Installing secondary post mounted left-turn signals.
- Installing exclusive left-turn lanes and/or permitted/protected left-turn signal phases, when needed.

It is important to note that when implementing permitted/protected left-turn signal phases, the guidelines used to justify the additional phase were less conservative, as compared to common practice in Michigan.

3. The ‘before’ and ‘after’ study of the groups of intersections with similar counter-measures resulted in the following statistically significant percent reductions:
    - Installation of all-red intervals and upgrading signal lenses to 12-inch diameters.
        - 72 % reduction in angle crashes.
    - Installation of exclusive left-turn lanes only.
        - 55 % reduction in left-turn head-on crashes.
    - Installation of exclusive left-turn lanes and phases.
        - 68% reduction in left-turn head-on crashes.
    - Installation of exclusive left-turn phase only.
        - 67% reduction in left-turn head-on crashes.

4. The isolated intersections which had a very high crash frequency during the ‘before’ period were also tested for the regression to the mean effects. No substantial regression to the mean effects were found.

5. In order to demonstrate that the ‘before and after’ study results are realistic in comparison to the results of other methods, ‘before and after studies with control sites’ and Empirical Bayes analyses were performed at selected intersections in City of Grand Rapids and City of Detroit for which suitable control sites were identified. Three statistical tests were performed to determine if significant crash reductions were observed at the test sites. The significant results of Poisson test, Chi-Square test and Paired t-test helped to conclude that the implemented countermeasures were effective in reducing the targeted crashes.

6. Economic analyses were performed to determine the benefit-cost ratio at all the intersections and corridors where improvements were made. The overall benefit-cost ratio for all the intersections and corridors combined, indicated that the accrued benefits are higher in dollar value than the incurred costs and resulted in the benefit-cost ratio of 16 to 1.

Based on the effectiveness evaluation of the treated sites, the specific safety improvements were successful in reducing the targeted crash types, thereby, reducing the total and injury crashes at these locations.

EVALUATION STUDIES FOR THE AAA ROAD IMPROVEMENT DEMONSTRATION PROGRAM IN MICHIGAN- FINAL REPORT

1.0 INTRODUCTION

In 1996, the Automobile Association of America (AAA), Automobile Club of Michigan initiated a Road Improvement Demonstration Program (RIDP) involving a public-private partnership to identify high crash locations and to develop and implement safety measures in the City of Detroit. An agreement was initiated between the City of Detroit and the Automobile Club of Michigan to form the public-private venture to improve roadway safety in the City. Later, the Southeast Michigan Council of Governments (SEMCOG), Wayne County, the Michigan Office of Highway Safety Planning (MOHSP) and the Michigan Department of Transportation (MDOT) became involved in this unique partnership. The agencies came together in a cooperative working arrangement to alleviate crashes and injuries at selected high crash intersections and some heavily traveled urban corridors. A Steering Committee was formed which consisted of representatives of the partners listed above to oversee the RIDP. The program was designed to enhance traffic safety by reducing the frequency and severity of crashes at high-risk urban intersections and corridors.

In 1997, a similar public-private partnership program was initiated in the City of Grand Rapids. The partners and Steering Committee members for this program include the Automobile Club of Michigan, the City of Grand Rapids and MDOT.

The RIDP includes the identification and study of safety deficiencies at a total of 300 intersections, including 250 intersections in the City of Detroit and 50 intersections in the City of Grand Rapids. Of the 300 total study intersections, improvements have been implemented at 172 thus far, including 137 intersections in Detroit and 35 intersections in Grand Rapids.

In order to perform the effectiveness evaluation, sufficient traffic crash data both before and after the implementation of the safety treatments is required. As a part of this study, data was available and had been accumulated for 85 intersections for a two to three-year ‘before’ period and approximately one to over four years of ‘after’ data. These intersections are the focus of this evaluation report. These 85 intersections represent approximately 28 percent of the total number of intersections included in the RIDP. The intersections were selected for inclusion in this evaluation study based on their implementation dates.

The Wayne State University-Transportation Research Group (WSU-TRG) received funding to perform the continuing effectiveness evaluation of the project intersections from MOHSP and the Automobile Club of Michigan.

Over the past few years, the WSU-TRG engineers have conducted an ongoing effectiveness evaluation of 85 study locations, including the following:

- 33 intersections along the Woodward Avenue corridor, 25 of which are located in the City of Detroit, and the remaining 8 are located in the City of Highland Park
- 8 intersections along the Grand River Avenue corridor in the City of Detroit
- 5 intersections along the Wyoming Road corridor in the City of Detroit
- 8 intersections along the Burton Street corridor in the City of Grand Rapids
- 9 intersections along the Eastern Avenue corridor in the City of Grand Rapids
- 9 intersections along the Division Avenue corridor in the City of Grand Rapids
- 11 isolated intersections in the City of Detroit:
    - Seven Mile Road and John R Road Intersection
    - Seven Mile Road and Ryan Road Intersection
    - Hubbell Road and Puritan Road Intersection
    - Schoolcraft Road and Evergreen Road Intersection
    - Davison Avenue and Linwood Avenue Intersection
    - Cadieux Avenue and I-94 Service Drive Intersections
    - Harper Avenue and Cadieux Avenue Intersection
    - Harper Avenue and Dickerson Road Intersection
    - Dexter Road and Davison Avenue Intersection
    - Schaefer Highway and McNichols Road Intersection
    - Seven Mile Road and Schaefer Highway Intersection

- 2 isolated intersections in the City of Grand Rapids:
    - Leonard Street and College Avenue Intersection
    - Michigan Street and Ottawa Avenue Intersection

2.0 STUDY OBJECTIVES

The objectives of this evaluation study are as follows:

- To determine the effectiveness of the safety improvements using a 'before and after' experimental plan at the corridors and intersections in the cities of Detroit and Grand Rapids.
- To determine the effectiveness of the safety improvements at selected intersections through the use of control site experiments.
- To determine the effectiveness of specific countermeasures and combination of safety treatments in alleviating traffic crash and injury problems.
- To perform an economic analysis of the implemented safety treatments at the study intersections.

This report includes the quantitative statistics and results of a 'before and after' (B&A) study of the safety improvements implemented at the six corridors and isolated intersections noted earlier. Also included are a sample of B&A with control studies, and evaluation using the Empirical Bayes (EB) method of estimating the safety effects at the same sample of intersections. Appropriate parametric statistical tests have also been performed to determine the effectiveness of the implemented countermeasures. Economic analyses were performed to determine economic effectiveness of the implemented safety improvements.

3.0 SITE DESCRIPTION AND IMPLEMENTED IMPROVEMENTS

The improvements implemented at the study intersections and corridors varied from location to location. However, in general they were low cost improvements. The isolated intersections included in this evaluation study were initially selected for improvements based on their past traffic crash experience and insurance claim experiences. The corridors were selected based on the crash experience at the major intersections. The minor intersections in the corridors typically experienced a low to moderate number of crashes. At the corridor level, relatively low cost improvements were implemented at all intersections, including the major and minor intersections. It is important to note that the midblock traffic crashes along the corridors were insignificant compared to the crashes at the signalized intersections. Therefore, they were not targeted for safety improvements as a part of this study.

The AAA insurance claims database was also used to select the intersection and corridor locations included in the Michigan RIDP. This database helped identify locations that experienced a high number of total crashes, as well as injury crashes, angle crashes and left-turn head-on crashes, which typically occur at urban intersections with high insurance claims.

The following provides a brief description of the corridors and isolated intersections included in this evaluation study, as well as a description of the implemented safety improvements.

Details of the improvements installed at each of the 85 study intersections are included in Appendix I.

3.1 Woodward Avenue Corridor

Woodward Avenue (M-1) is a north-south state trunkline in the cities of Detroit and Highland Park, Michigan. The study corridor is approximately seven and a half miles long and extends from Sibley/Adelaide Street to State Fair Avenue. The posted speed limit on Woodward Avenue is 35 miles per hour (mph), south of McNichols Road and 40 mph north of this road. The corridor contains 33 signalized intersections, as shown in Figure 1.

Woodward Avenue is a seven-lane arterial street north of Grand Boulevard to McNichols Road, and a nine-lane arterial south of Grand Boulevard, consisting of three to four lanes in the north and southbound directions and a center lane for left turns. Left-turn lanes were also present at each of the signalized intersections at the Woodward Avenue approaches. North of McNichols Road, Woodward Avenue becomes a divided highway with four lanes of traffic in each direction. Direct left turns are prohibited at the intersections. Drivers must make indirect left turns using the directional crossovers located downstream of the intersection. On-street parking was generally permitted throughout the corridor, with no parking restrictions in close proximity to the intersections.

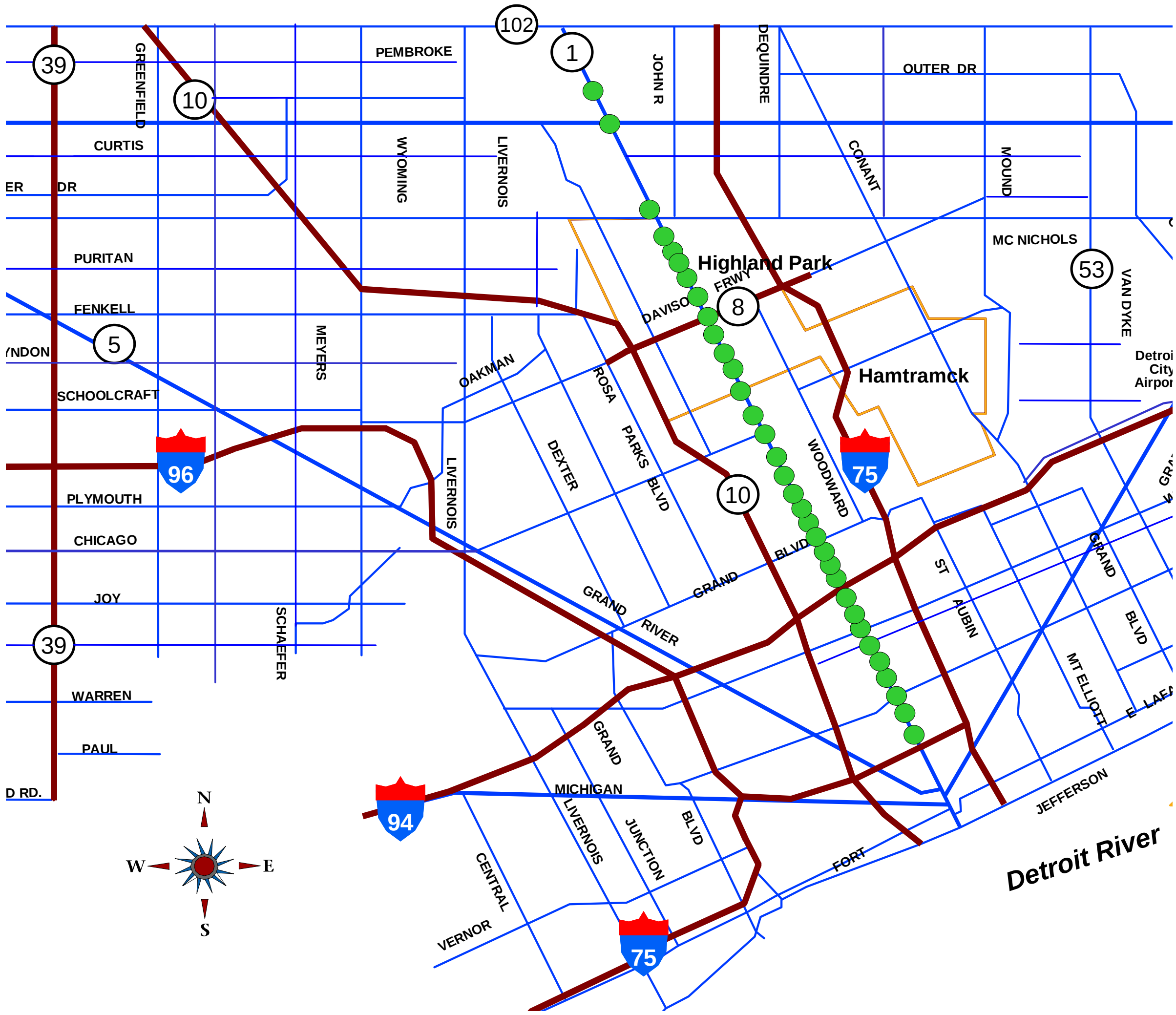


Figure 1. Site Map of the Woodward Avenue Corridor

The implemented improvements along the Woodward Avenue corridor were related to the traffic signal design and installation. No geometric improvements were made along the Woodward Avenue corridor. The following improvements were made:

- Modified the signal timing at all intersections based on current traffic volume data.
- Implemented all-red intervals in the signal timing design ranging from 1.0 to 2.0 seconds on Woodward Avenue and 1.5 seconds on the cross-streets.
- Replaced all 8-inch signal lenses with 12-inch signal lenses, even though the speed limit on Woodward Avenue does not exceed 40 mph. Please note that the Michigan Manual of Uniform Traffic Control Devices (MMUTCD) *(1)* recommends 12-inch signal lenses be used when the 85th percentile speed exceeds 40 mph.

- Relocated the signal heads to improve visibility.
- Modified signal timing to provide arterial progression from Sibley/Adelaide Street to Ferris Street.

Sample views of the Woodward Avenue corridor, before and after the installation of the improvements are shown in Photographs 1 through 4.

Photograph 1. Woodward Avenue at Milwaukee Street (‘Before’ Condition)

Photograph 2. Woodward Avenue at Milwaukee Street (‘After’ Condition)

Photograph 3. Warren Avenue at Woodward Avenue (‘Before’ Condition)

Photograph 4. Warren Avenue at Woodward Avenue (‘After’ Condition)

3.2 Grand River Avenue Corridor

Grand River Avenue is a major arterial roadway in the City of Detroit, which runs northwest-southeast through the city. It is a part of the state trunk line system (M-5) under the jurisdiction of MDOT. The corridor provides access to many business and connectivity to the freeway system. The posted speed limit on Grand River Avenue is 35 miles per hour (mph). The study corridor contains 8 signalized intersections from McIntyre Street to Warwick Street, a stretch of two miles, in the City of Detroit, as shown in Figure 2.

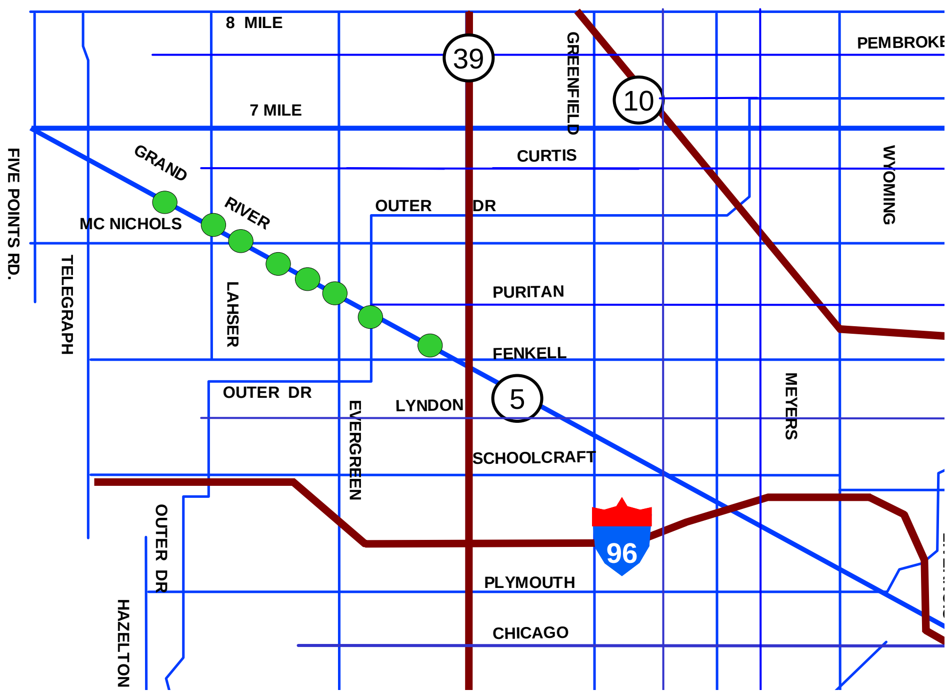


Figure 2. Site Map of the Grand River Avenue Corridor

Grand River Avenue is a seven-lane arterial street west of McNichols Road, including three through lanes in each direction of travel and a center-lane for left turns. East of McNichols Road, Grand River Avenue is a six-lane road without a continuous center lane for left turns. However, left-turn lanes are present at each of the signalized intersections at the Grand River Avenue approaches except for the Grand River Avenue and McNichols Road intersection. Left turns are prohibited on Grand River Avenue at McNichols Road. On-street parking was generally permitted throughout the corridor, with no parking restrictions in close proximity to the intersections.

The implemented improvements along the Grand River Avenue corridor were related to the traffic signal design and installation. No geometric improvements were made along the Grand River Avenue corridor and thus, remains the same as described earlier. The following improvements were installed:

- Modified the signal timing at all intersections based on current traffic volume data.
- Installed 12-inch signal lenses at all approaches, even though its not specifically required according to the MMUTCD *(1)*, since the speed limit does not exceed 40 mph.
- Installed low-level far right signal heads and pedestrian signals at the Grand River Avenue approaches for all the intersections.
- Installed left-turn case signs over the exclusive left-turn lanes at all the intersections.
- Relocated the signal heads to improve visibility.

Sample views of the Grand River Avenue corridor, before and after the installation of the improvements are shown in Photographs 5 through 8.

Photograph 5. Grand River Avenue at Burt Road ('Before' Condition)

Photograph 6. Grand River Avenue at Burt Road ('After' Condition)

Photograph 7. Grand River Avenue at Lahser Road ('Before' Condition)

Photograph 8. Grand River Avenue at Lahser Road ('After' Condition)

3.3 Wyoming Road Corridor

Wyoming Road is a two-lane urban arterial with a variety of roadway geometries at the intersection approaches. There are numerous driveways providing access to the adjacent properties along the road. The Wyoming Road study corridor is three and a half miles long from Schoolcraft Road to Seven Mile Road and contains five signalized intersections as shown in Figure 3. The surrounding land use along the Wyoming Road corridor is predominantly residential and commercial. Restaurants, gasoline stations, strip commercial centers and grocery stores characterize this area especially near the major intersections. The speed limit on Wyoming Road is posted at 30 mph.

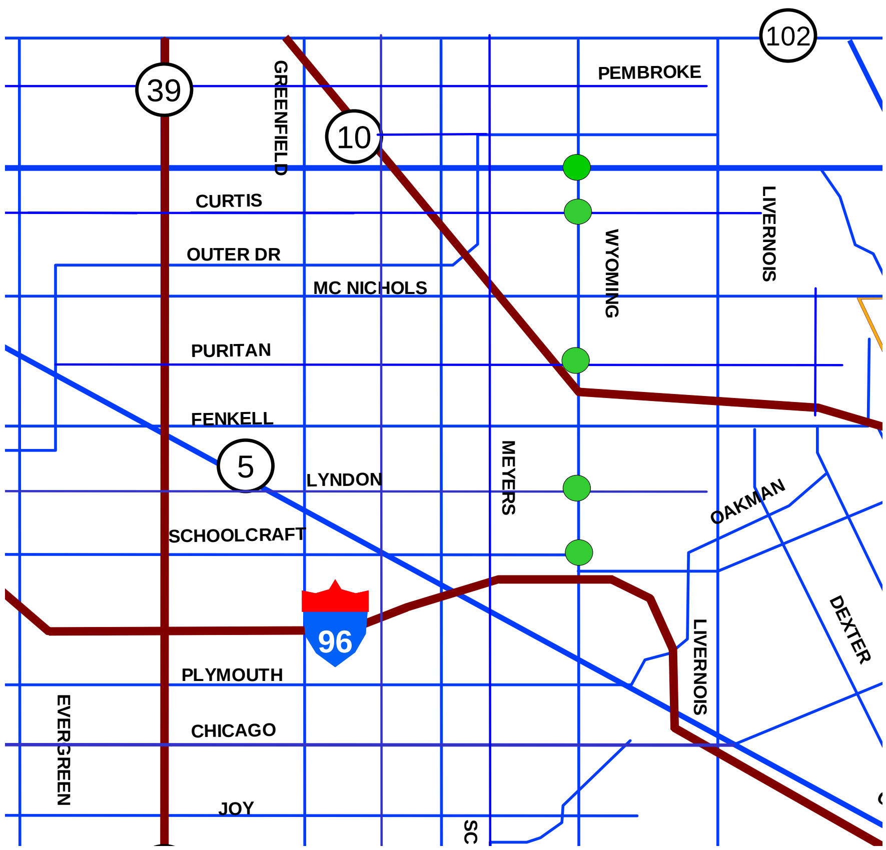


Figure 3. Site Map of the Wyoming Road Corridor

The implemented improvements along the Wyoming Road corridor were related to intersection geometry, and the traffic signal design and installation.

The following improvements were installed:

- Modified the signal timing at all intersections based on current traffic volume data.
- Installed 12-inch signal lenses at all approaches, even though it is not specifically required according to the MMUTCD *(1)*, since the speed limit on this road does not exceed 40 mph.
- Added exclusive left-turn lanes at the following intersections: Wyoming Road and Curtis Road, Wyoming Road and Lyndon Road, Wyoming Road and Puritan Road, and Wyoming Road and Schoolcraft Road.
- Installed permissive/protected left-turn phases at the intersections at Lyndon Road, Puritan Road, Schoolcraft Road, and Seven Mile Road.
- Installed all-red intervals of lengths calculated as per the Institute of Transportation Engineers (ITE) guidelines *(2)* [ARI = (W+L)/V, where ARI is the length of the all-red interval in seconds, W is the intersection width in feet, L is the length of the clearing vehicles in feet and V is the approach speed in feet per second].
- Removed the "No Left-Turn" restrictions.
- Installed low level left-turn signals at all intersections.
- Installed left-turn case signs over the exclusive left-turn lanes where left-turn phases were not provided.

Sample views of the Wyoming Road corridor for the 'before' and 'after' periods are shown in Photographs 9 through 12.

Photograph 9. **Westbound Wyoming Road at Puritan Road ('Before' Condition)**

Photograph 10. **Westbound Wyoming Road at Puritan Road ('After' Condition)**

Photograph 11. Westbound Wyoming Road at Schoolcraft Road ('Before' Condition)

Photograph 12. Westbound Wyoming Road at Schoolcraft Road ('After' Condition)

3.4 Burton Street Corridor

Burton Street is a major east-west arterial street in the City of Grand Rapids, Michigan. This study corridor is approximately four and a half miles in length from Buchanan Avenue to Raybrook Avenue, containing ten signalized intersections. This evaluation study included eight of the ten signalized intersections, as shown in Figure 4. The speed limit along Burton Street is posted at 30 to 35 mph.

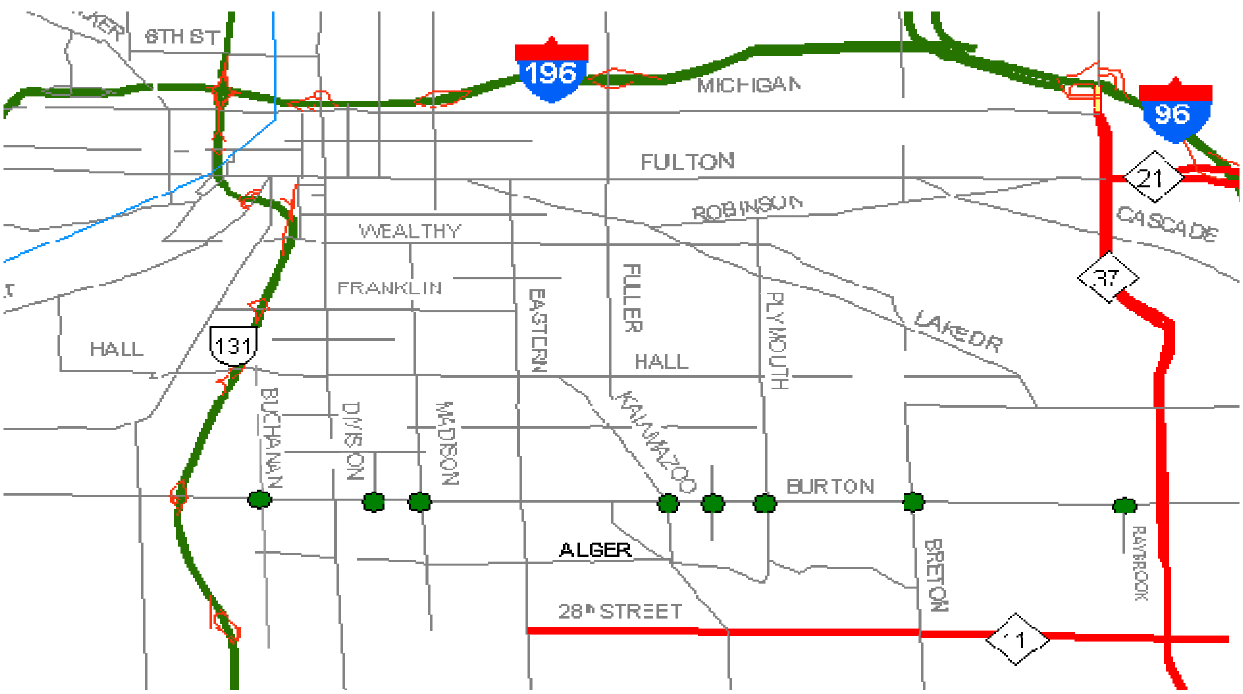


Figure 4. Site Map of the Burton Street Corridor

In the ‘before’ condition, Burton Street primarily had five lanes at the signalized intersections, with two lanes for eastbound travel, two lanes for westbound travel and exclusive left-turn lanes, with exceptions at the intersections of Jefferson Avenue, Sylvan Avenue and Raybrook Avenue. On-street parking was generally prohibited throughout the Burton Street corridor. At the Burton Street intersections at Jefferson Avenue and Raybrook Avenue, Burton Street consisted of four lanes, with two lanes for each direction of travel and no exclusive left-turn lanes. At the Sylvan Avenue intersection, Burton Street had two lanes for westbound travel, two lanes for eastbound travel and an eastbound exclusive right-turn lane.

The improvements implemented along the Burton Street corridor did not include any major geometric improvements. Thus, the laneage described in the ‘before’ period is the same as that in the ‘after’ period. The safety treatments include the following:

- Replaced existing span wire signal configuration with box span configuration of signal support.
- Relocated signal heads over the travel lanes (one display per lane) to improve visibility.
- Replaced 8-inch signal lenses with 12-inch signal lenses, even though the speed limit on Burton Street does not exceed 40 mph.
- Installed black back plates on signals to improve visibility.
- Installed secondary post mounted signal heads to improve visibility for left-turn traffic.
- Installed permissive/protected left-turn phasing for all approaches on the Burton street intersections at Buchanan Avenue, Madison Road, Kalamazoo Avenue and Plymouth Road.
- Modified the signal timing at all intersections based on current traffic volume data.
- Installed all-red intervals of lengths calculated as per the ITE guidelines *(2).*

Perspective views of two sample intersections along the Burton Street corridor for the ‘before’ and ‘after’ conditions are shown in Photographs 13 through 16.

Photograph 13. Westbound Burton Street at Buchanan Avenue ('Before' Condition)

Photograph 14. Westbound Burton Street at Buchanan Avenue ('After' Condition)

Photograph 15. Westbound Burton Street at Kalamazoo Avenue ('Before' Condition)

Photograph 16. Westbound Burton Street at Kalamazoo Avenue ('After' Condition)

3.5 Eastern Avenue Corridor

Eastern Avenue is a north-south corridor in the City of Grand Rapids. This study corridor is approximately three miles in length from Alger Street to Lake Drive, containing nine signalized intersections, as shown in Figure 5. The speed limit along Eastern Avenue is posted at 30 mph.

Eastern Avenue is primarily a two-lane roadway that, in the 'before' period widened to three lanes, at five of the nine intersections to accommodate north-south left-turn lanes including the Eastern Avenue intersections at Hall Street, Franklin Street, Wealthy Street, Burton Street, and Alger Street. On-street parking is also permitted at several locations throughout this corridor.

Figure 5. Site Map of Eastern Avenue Corridor

As a part of the improvements, exclusive left-turn lanes were added to some of the intersection approaches. This included the east and westbound approaches of the Eastern Avenue intersections at Franklin Street, Wealthy Street and Hall Street; the north and southbound approaches at the Eastern Avenue and Lake Drive intersection; and at all four approaches of the Eastern Avenue intersections at Cherry Street, Oakdale Street and Sherman Street. In addition to these, the following improvements were implemented at the Eastern Avenue corridor intersections:

- Replaced existing span wire mounted signal configuration with box span installation
- Relocated signal heads to improve visibility.
- Replaced 8-inch signal lenses with 12-inch signal lenses, even though the speed limit on Eastern Avenue does not exceed 40 mph.
- Modified the signal timing at all intersections based on current traffic volume data.
- Implemented all-red intervals of lengths calculated as per the ITE guidelines *(2)* at locations where needed (Eastern Avenue 2.0 seconds; cross-streets 2.0 seconds).

- Installed back plates on signals to improve visibility at Lake Drive.
- Installed semi-actuated permissive/protected left-turn phases at all approaches on Eastern Avenue intersections at Wealthy Street, Franklin Street, Lake Drive and Alger Street.
- Installed secondary post mounted signal heads to improve visibility for left-turn traffic.

Perspective views of two sample intersections along the Eastern Avenue corridor for the 'before' and 'after' conditions are shown in Photographs 17 through 20.

Photograph 17. Eastern Avenue and Franklin Street ('Before' Condition)

Photograph 18. Eastern Avenue and Franklin Street ('After' Condition)

Photograph 19. Eastern Avenue and Sherman Street ('Before' Condition)

Photograph 20. Eastern Avenue and Sherman Street ('After' Condition)

3.6 Division Avenue Corridor

Division Avenue is a major north-south arterial in the City of Grand Rapids. The study corridor is approximately two and a half miles in length and extends from Weston Street to Burton Street, containing nine signalized intersections, as shown in Figure 6. The speed limit along Division Avenue is posted at 25 to 30 mph.

The Division Avenue corridor is a four-lane road with two lanes each, for north and southbound travel. On-street parking is also permitted along the corridor, except near the intersection approaches where parking is prohibited. In the 'before' period, there were north and southbound left-turn lanes at five of the nine study intersections, including the Division Avenue intersections at Weston Street, Oakes Street, Wealthy Street, Franklin Street and Delaware Street.

Figure 6. Site Map of the Division Avenue Corridor

As a part of the improvements, exclusive left-turn lanes were provided at the north and southbound approaches of the Division Avenue intersections at Burton Street and at Hall Street, and at the east and westbound approaches of the Division Avenue and Franklin Street intersection. In addition, the following improvements were implemented along the Division Avenue corridor:

- Relocated signal heads to improve visibility by providing one set of signal displays for each lane of travel.
- Modified the signal timing at all intersections based on current traffic volume data.
- Implemented all-red intervals in the signal timing design ranging from 1.2 to 2.5 seconds on Division Avenue and 1.2 to 2.0 seconds on minor streets.
- Replaced 8-inch signal lenses with 12-inch signal lenses, even though the speed limit on Division Avenue is only 25 mph to 30 mph.
- Installed left-turn phasing for Division Avenue intersections at Burton Street, Hall Street, Franklin Street and Wealthy Street.
- Installed secondary post mounted signal heads at some intersections to improve visibility for left-turn traffic.
- Box span configuration replaced the existing diagonal span at Burton Street, Franklin Street, Delaware Street and Wealthy Street.
- Installed a third overhead display at Oakes Street, Weston Street, Cherry Street and Delaware Street.

Perspective views of two sample intersections in the Division Avenue corridor for the 'before' and 'after' condition are shown in Photographs 21 through 24.

Photograph 21. Division Avenue and Burton Street ('Before' Condition)

Photograph 22. Division Avenue and Burton Street ('After' Condition)

Photograph 23. Division Avenue and Cottage Grove ('Before' Condition)

Photograph 24. Division Avenue and Cottage Grove ('After' Condition)

3.7 Isolated Intersections

A total of 11 signalized intersections in the City of Detroit and two in City of Grand Rapids were included in this evaluation study, which include the following intersections:

- Eleven isolated intersections in the City of Detroit (refer to Figure 7):
  - Seven Mile Road and John R Road
  - Seven Mile Road and Ryan Road
  - Hubbell Road and Puritan Road
  - Schoolcraft Road and Evergreen Road
  - Davison Avenue and Linwood Avenue
  - Cadieux Avenue and I-94 Service Drive
  - Dexter Road and Davison Avenue
  - Schaefer Highway and McNichols Road
  - Seven Mile Road and Schaefer Highway
  - Harper Avenue and Cadieux Avenue
  - Harper Avenue and Dickerson Road

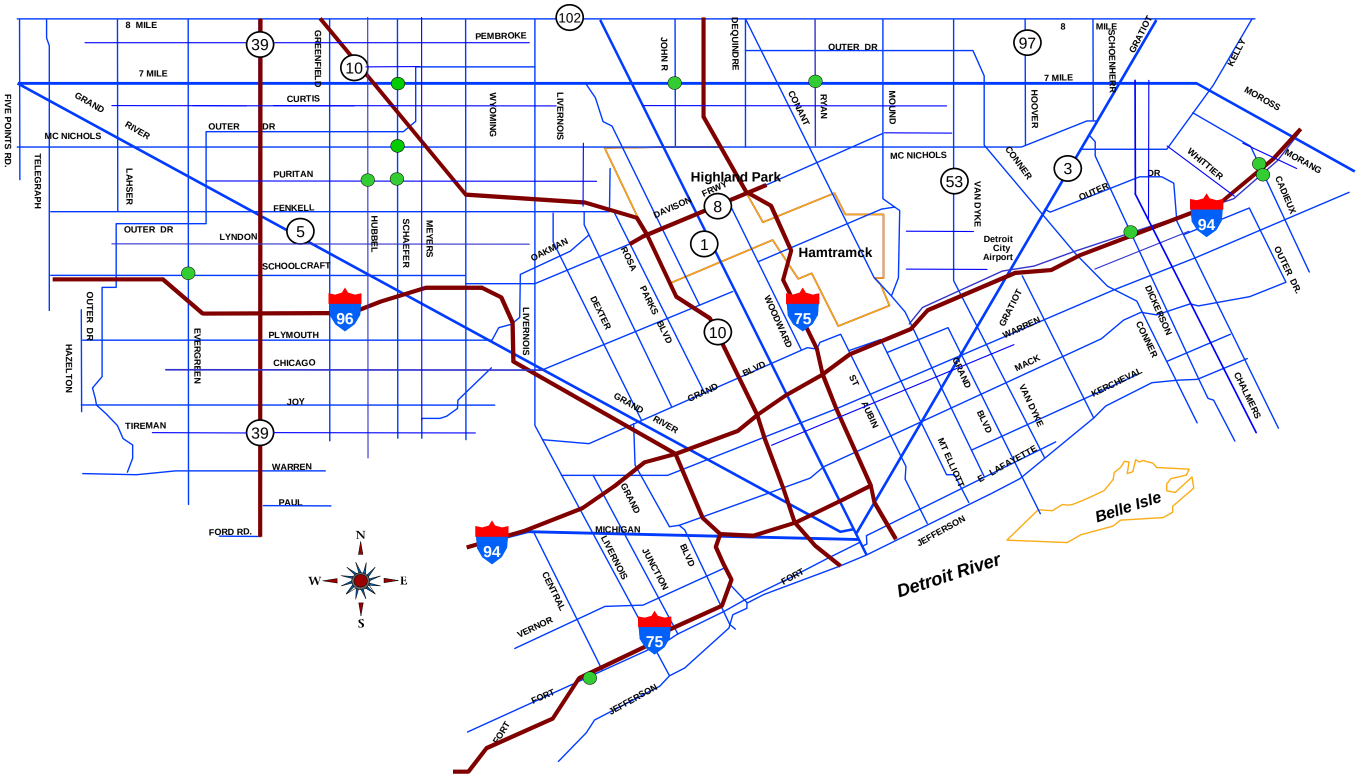


Figure 7. Site Map of the Isolated Intersections in the City of Detroit

Two isolated intersections in the City of Grand Rapids (refer to Figure 8):

- Leonard Street and College Avenue
- Michigan Street and Ottawa Avenue

In general, the improvements installed at the isolated intersections included the following:

- Repaved some of the intersection approaches.
- Installed exclusive left-turn lanes.
- Installed exclusive left-turn phases, where needed.
- Replaced 8-inch signal lenses with 12-inch signal lenses.
- Modified signal timing based on current traffic volume data and provided all-red intervals of lengths calculated as per the ITE guidelines *(2)*.
- Eliminated on-street parking in close proximity of the intersections.

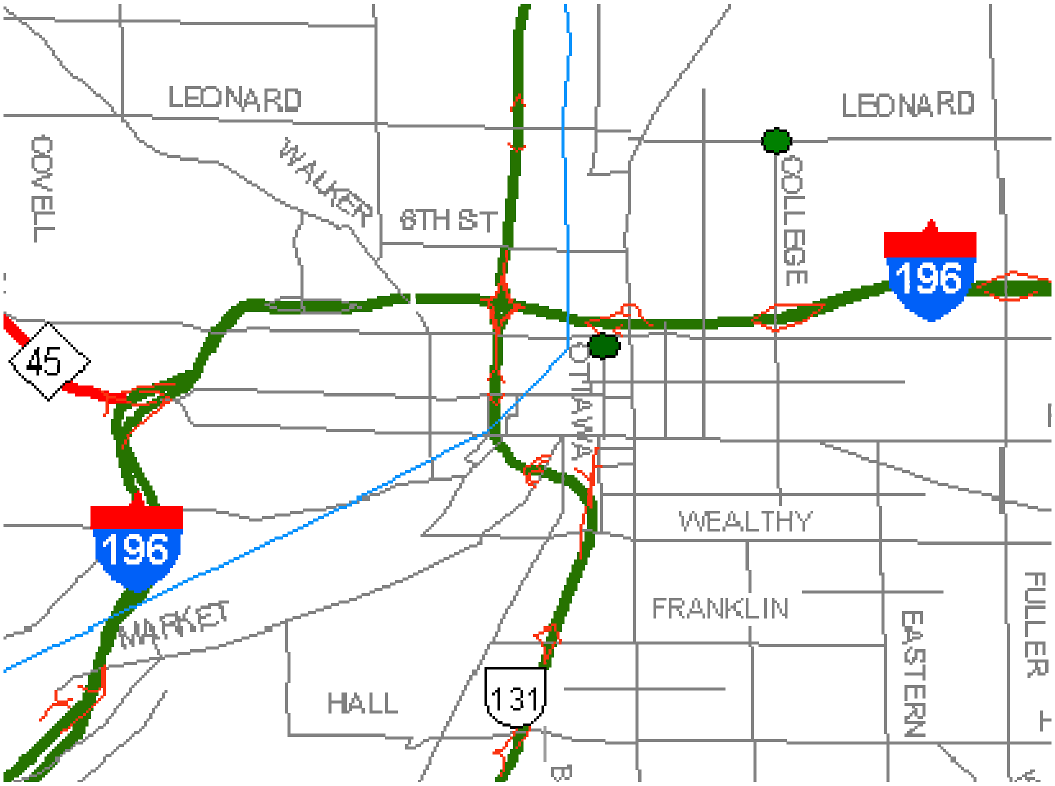


Figure 8. Site Map of the Isolated Intersections in the City of Grand Rapids

Perspective views of one of the isolated intersections in the City of Detroit, the intersection of Harper Avenue and Cadieux Avenue, for the 'before' and 'after' condition are shown in Photographs 25 and 26.

Photograph 25. Eastbound Harper Avenue at Cadieux Avenue ('Before' Condition)

Photograph 26. Eastbound Harper Avenue at Cadieux Avenue ('After' Condition)

Two of the 13 isolated intersections were excluded from the evaluation study, which include the intersections of Linwood Avenue and Davison Avenue, and Michigan Street and Ottawa Avenue. The following provides the rationale for eliminating these intersections from the study.

Linwood Avenue and Davison Avenue

At the southwest corner of the intersection of Linwood Avenue and Davison Avenue, a grocery store and a fast-food restaurant have recently been developed. The recent commercial developments at the corners of the intersection have changed the characteristics of the intersection, as well as the traffic flow. In addition, Wayne County had taken over the operation and maintenance of this signal during the ‘after’ period, and removed the all-red intervals from the newly implemented signal timings.

It is not appropriate to perform an effectiveness evaluation including the B&A or the B&A with control studies at this location since the comparison between the ‘before’ and ‘after’ condition is no longer valid.

In a B&A or B&A with control experimental plan, there should not be any changes in the roadway geometry, traffic control or land use characteristics, which may impact traffic movements. Unfortunately, the new land uses have completely changed the traffic patterns and the elimination of appropriate all-red intervals has forced this intersection to be excluded from the evaluation study.

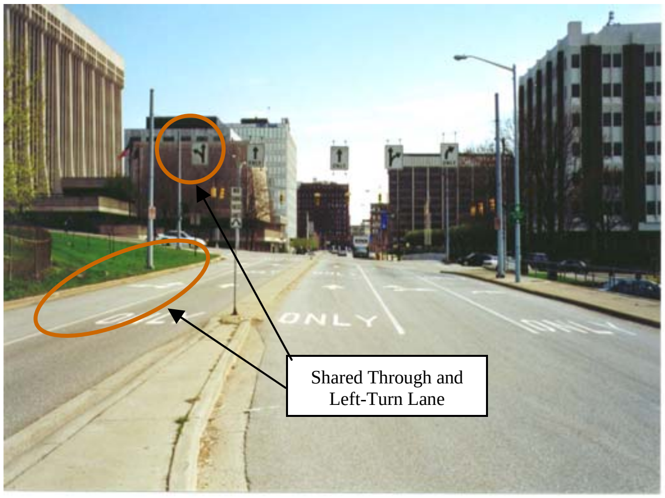
Michigan Street and Ottawa Avenue

The intersection of Michigan Street and Ottawa Avenue is located at the end of the I-196 off-ramps south of the I-196 interchange in the Central Business District (CBD) of Grand Rapids. Ottawa Avenue is a southbound one-way street containing four to five lanes. Michigan Street is a six-lane east-west street. The roadway configuration leading to the intersection is complex. North of the intersection there are two freeway interchange exits from I-196 to access eastbound and westbound Michigan Street, as well as traffic lanes dedicated for Ottawa Avenue traffic. A raised median island is located in the center of the roadway at the southbound approach to prevent ramp traffic from weaving over several lanes to turn left.

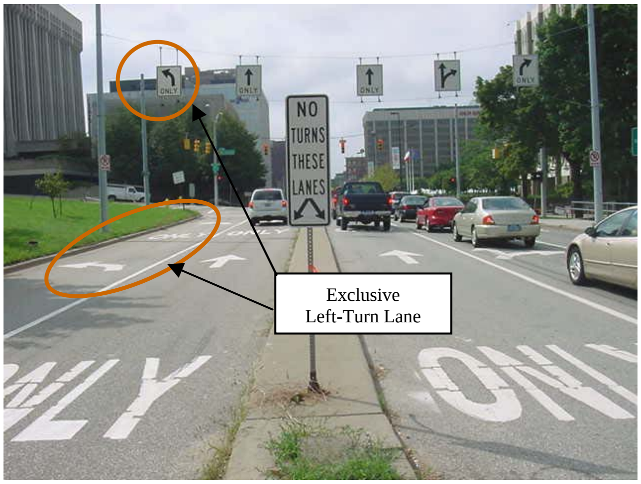
Due to the complex nature of this intersection, unique countermeasures were proposed to mitigate the high number of crashes occurring at the southbound approach. However, the critical safety improvements that were recommended at this intersection were not installed. One of which included revising the signal timing and phasing plan, which was key in separating the through and left-turning traffic. The only improvements implemented included:

- Installing loop detectors for westbound left-turn traffic
- Changing the southbound left and through shared lane to an exclusive left-turn lane with an overhead left-turn only (R3-7) sign and pavement markings.

Therefore, the crash experience is not expected to change since the critical improvements were not installed. Thus, it was not included in the evaluation study. The characteristics of the southbound Ottawa Avenue approach at Michigan Street, for the 'before' and 'after' periods are shown in Photographs 27 and 28.



Photograph 27. Southbound Ottawa Avenue at Michigan Street ('Before' Condition)



Photograph 28. Southbound Ottawa Avenue at Michigan Street ('After' Condition)

4.0 DATA COLLECTION

The traffic study reports for each of the intersections and corridors prepared by various consultants were obtained and reviewed, in order to identify the following:

- Pre-improvement intersection geometry, traffic volumes and traffic control characteristics
- Pre-improvement identified safety deficiencies and targeted crash types and severity
- Proposed countermeasures

The actual improvement plans for each of the intersections and corridors were obtained, where available, and reviewed to identify the implemented countermeasures. This review indicated that most, but not all, of the proposed countermeasures were installed.

Extensive traffic crash data was collected at each of the 85 intersections for two years of 'before' data, and for as much 'after' data, as was available. If the 'after' period was less than a year, the 'before' data was analyzed for the same months as the 'after' period in order to avoid temporal variations in the crash frequencies. The resulting crash frequencies were then converted to annual averages for both the 'before' and 'after' periods. When over one year of 'after' crash data was available, the crash frequencies were converted to annual averages. Subsequently, the 'before' data used consisted of the annual average of two years of data. It is important to note that when the crash frequencies are normalized over a year, it is possible that the annual frequencies may be over or under represented due to seasonal variations. For the majority of the intersections, the 'after' period included two or more winter seasons and thus, the effect of seasonal variations will not materially alter the conclusions of this study.

The intersection crashes considered in this study included all crashes within a radius of 150 feet from the centerline of the intersection. Since the police traffic crash reports were used in this evaluation study, the data was collected from the respective city offices and the 'before' and 'after' crash records were established. All crash types were determined from the diagrams prepared by the police officers on the UD-10 form and/or from the direction of movements of the involved drivers as noted in the crash report forms. The crash diagrams included on the crash report provided an accurate assessment of the type of crash that actually occurred, regardless of the crash type coded on the form.

5.0 TRAFFIC CRASH ANALYSIS

Traffic crash data from the police traffic crash reports (UD-10 forms) were collected for the 'before' and 'after' implementation periods. Since the state of Michigan's computerized database inherently contains errors related to crash type and crash location, crash data from the UD-10 police report forms were analyzed in order to determine accurate crash types and crash locations.

For the 'before' period, historic traffic crash data was collected for a two-year period for the majority of the intersections. In some instances and for only a few intersections, slightly less data was used. Traffic crash data for the 'after' period was collected one month after the installation of the countermeasures and was continually collected on a monthly basis, as soon as the traffic crash reports became available. As a part of this evaluation study, the WSU-TRG engineers thoroughly analyzed each and every UD-10 crash report form in order to determine how and where the crash actually happened. This was done by examining the crash diagrams and remarks contained in the UD-10 forms, the direction of travel of the involved vehicles, and the intent of the drivers before the first impact.

By analyzing the UD-10 traffic crash reports, many errors in terms of the proper coding of the type of crashes, as well as the precise location of crashes were revealed. For example, a common error found in the traffic crash reports involves police officers coding left-turn head-on crashes as angle crashes. In left-turn head-on crashes, the initial direction of travel of the two impacted vehicles, are in the opposite direction. Whereas, the initial direction of travel for an angle crash is always perpendicular to each other. Besides, the sketch diagrams included on the crash report form almost always showed the correct picture of the crashes. Therefore, the crash types used in this study eliminated errors associated with the computerized crash database, which have been found to account for up to 30 percent error *(3)*.

It is also important to note that the intersection-related crashes and driveway-related crashes were analyzed as different and separate crash types. For example, the angle crash category included in this report only includes the angle crashes that occurred at the intersection. The angle crashes that occurred at driveway locations were coded as ‘other’ crashes. Theses crashes were analyzed separately since the probable causes and countermeasures for mitigating intersection-related angle crashes and driveway-related angle crashes are different. Thus, the crash analysis as performed in this study provide an accurate assessment of the effectiveness of the implemented intersection treatments.

Performing the effectiveness evaluation of the impacted crash types including angle, left-turn head-on, and injury crashes at a location or corridor, indirectly considers changes in the total crashes, as well as other crash types including sideswipe crashes, fixed objects crashes, rear end crashes.

The traffic crash data for each location was analyzed for the ‘before’ and ‘after’ periods, based on the police traffic crash reports. The traffic crash experience at each study location was determined through the examination of every traffic crash report. The crash locations for each intersection were then summarized on collision diagrams, for both the ‘before’ and ‘after’ periods. These diagrams were prepared in order to determine if the targeted crash types were mitigated by the implemented improvements. In general, the targeted crash types included angle, left-turn head-on and injury crashes, which also affected the total number of crashes.

Traffic crash data was also collected and analyzed at similar intersections in the cities of Detroit and Grand Rapids, where improvements were not implemented. The purpose of using these similar sites is as follows:

- To select some of these intersections as control sites, which are matched with selected test sites in order to perform a ‘before and after with control’ study
- To use the crash experience at similar sites in the Empirical Bayes method to reduce potential regression-to the mean effects.

The traffic crash frequencies by type and by severity were identified for each of the test intersections. Graphs showing the ‘before’ and ‘after’ crash frequencies were then prepared for each intersection and also on a corridor basis, where applicable.

5.1 Results of Traffic Crash Analyses for the Corridors

5.1.1 *Woodward Avenue Corridor – City of Detroit*

At the majority of the intersections along the Woodward Avenue corridor, reductions in total crashes were observed after the implementation of the safety treatments. However, at eight of the intersections, the total crashes increased. They include the intersections of Sibley/Adelaide Street, Mack Avenue/Martin Luther King (MLK), Parsons Street, Tuxedo/Tennyson Street, Courtland Street (by a fraction of a crash), Glendale/McLean Street, Buena Vista Street and Gerald Street, as shown in Figure 9.

It is important to note that at the intersection of Woodward Avenue and Mack Avenue, the traffic crashes increased from an annual average of 19 in the ‘before’ period, to an annual average of 25.8 in the ‘after’ period (Figure 9). In the pre-implementation safety study report performed by Hamilton Associates Consulting Ltd., the number of ‘before’ crashes at this intersection were reported as an annual average of approximately seven crashes per year, based on the data obtained from the computerized crash database. This was reported in the “Woodward Avenue Corridor Traffic Operations and Safety Review” report. Thus, based on the lower crash frequency obtained from the computerized crash database, no site-specific improvements were recommended. This may have resulted in a gradual increase in the number of crashes in the ‘after’ period.

It is important to note that at the corridor level, all the signalized intersections received similar countermeasures, irrespective of their historical crash experiences. They consist of both high crash locations and very low crash locations. Therefore, chances of having ‘regression to the mean’ in the crash and injury experience are quite low.

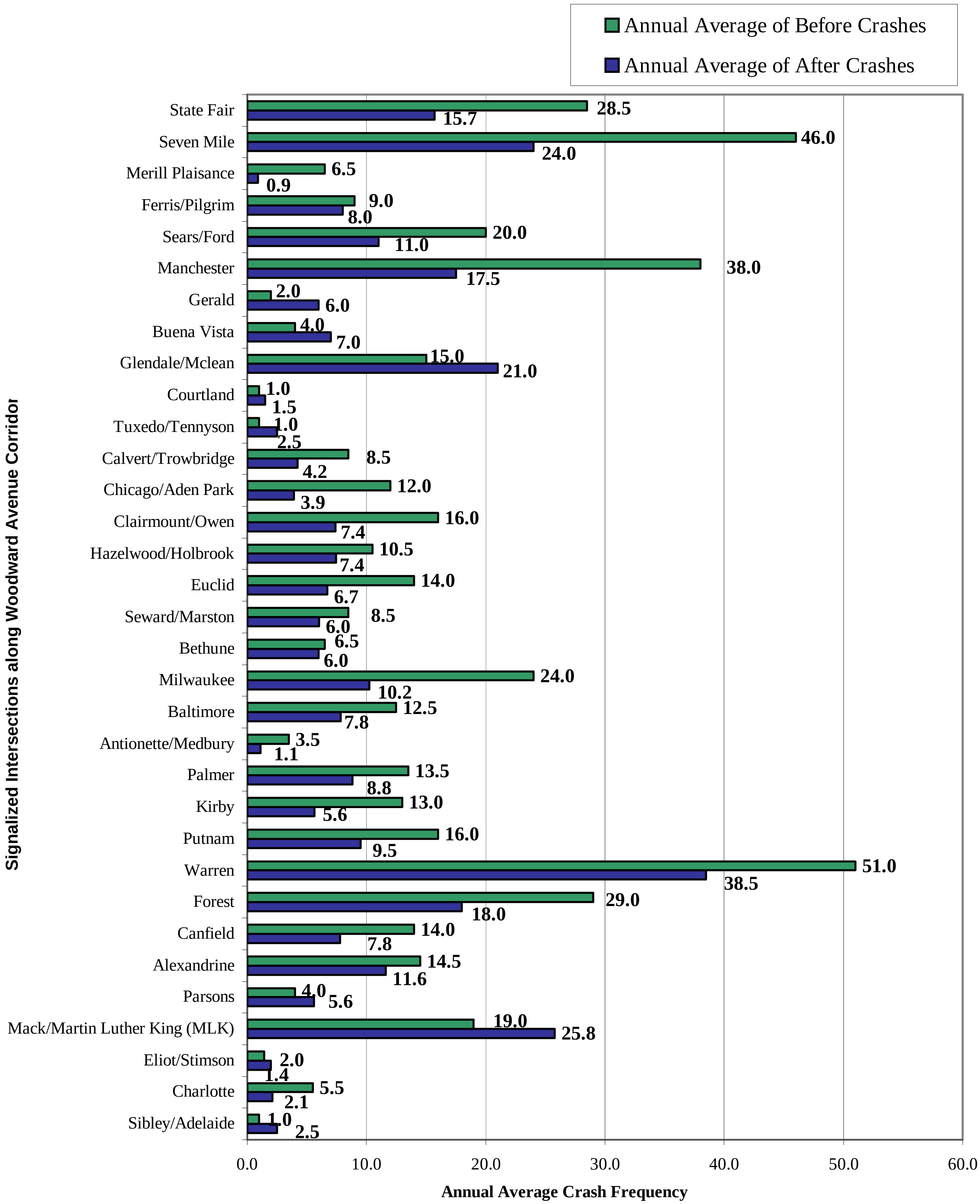


Figure 9. Comparison of Total Crashes for the Woodward Avenue Corridor Intersections

The ‘after’ periods used in this evaluation are as follows:

- Traffic crash data for the ‘after’ period was analyzed from November 1999 to August 2002 (34 months of data) for the Woodward Avenue corridor intersections from Sibley/Adelaide Street to Hazelwood/Holbrook in the City of Detroit.

- Traffic crash data for the ‘after’ period was analyzed from November 1999 to October 31, 2001 (24 months of data) for eight of the 11 intersections along the Woodward Avenue corridor in the City of Highland Park. The three exceptions include the Woodward Avenue intersections at Chicago/Aden Park, Calvert/ Trowbridge and Clairmount/Owen. For these three intersections, 34 months of data was available for the ‘after’ period from November 1999 to August 2002.

- The ‘after’ crash data was analyzed from August 2001 to August 2002 (13 months of data) for the Woodward Avenue corridor intersections at State Fair Road, Seven Mile Road and Merrill Plaisance Road.

The safety treatments implemented along the Woodward Avenue corridor were intended to reduce angle crashes and injury crashes at all the signalized intersections, which in turn would impact the total crashes. Figure 10 shows an overall reduction in the angle, injury, total and other crash types for the Woodward Avenue corridor intersections. Details of the ‘before and after’ crash analysis, including details showing the crash frequencies for angle and injury crashes for each of the intersections are included in Appendix II.

At a corridor level, the percent reductions for the targeted crash types, as shown in Figure 10 for the Woodward Avenue corridor indicate that the safety treatments had a positive effect in improving safety:

- Angle crashes reduced by 76 percent
- Injury crashes reduced by 46 percent
- Total crashes reduced by 33 percent

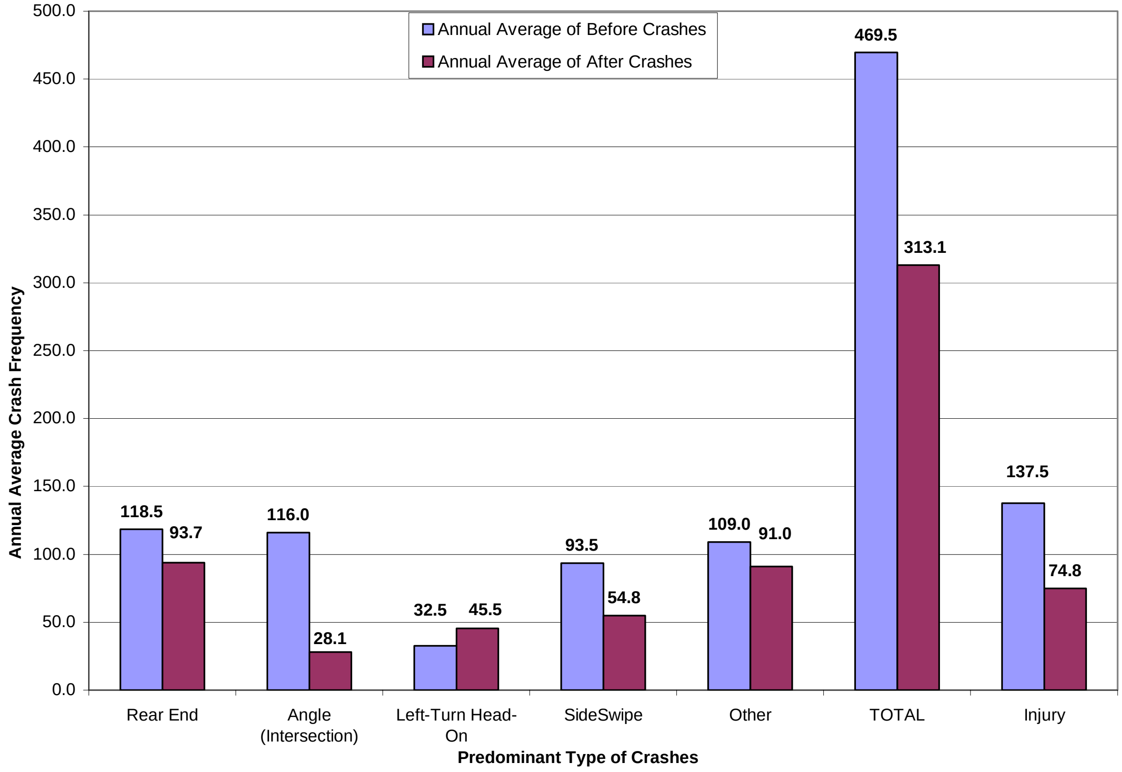


Figure 10. Comparison of Crash Types for the Woodward Avenue Corridor (Includes 33 Signalized Intersections)

5.1.2 Grand River Avenue Corridor – City of Detroit

Of the eight study intersections along the Grand River Avenue corridor, reductions in total crashes were observed at four of the intersections after the implementation of the safety treatments. At the remaining half of the intersections, the total crashes increased. They include the intersections of Burt (only by a fraction of a crash), Lahser, Outer Drive and Warwick (only by a fraction of a crash), as shown in Figure 11.

Traffic crash data for the 'after' period for the Grand River Avenue corridor was analyzed from August 2001 to August 2002 (13 months of data).

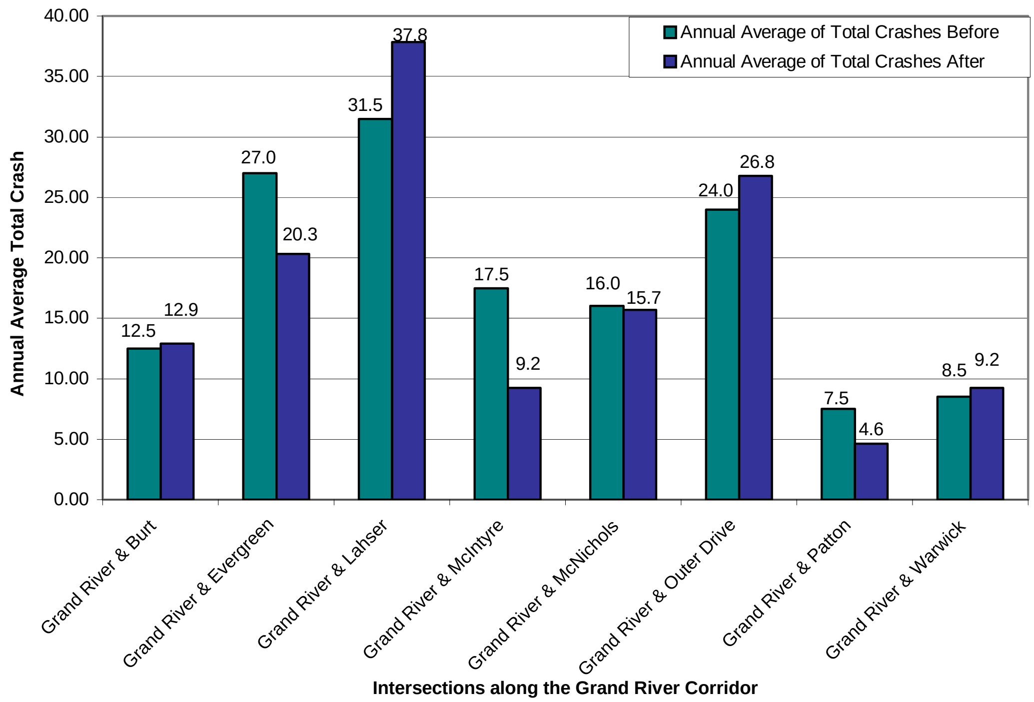


Figure 11. Comparison of Total Crashes for the Grand River Avenue Corridor Intersections

The safety treatments implemented along the Grand River Avenue corridor were intended to reduce left-turn head-on, angle and injury crashes at the signalized intersections, which in turn would impact the total crashes. Figure 12 shows an overall reduction in left-turn head-on and total crashes for the Grand River Avenue corridor intersections. The angle crashes and injury crashes increased in the 'after' period, which was not expected.

Details of the 'before and after' crash analysis, including bar charts showing the crash frequencies for angle, left-turn head-on and injury crashes for each of the Grand River Avenue corridor intersections are included in Appendix III.

At a corridor level, the percent reductions for the targeted crash types, as shown in Figure 12 are as follows:

- Left-turn head-on crashes reduced by 16 percent
- Total crashes reduced by 6 percent

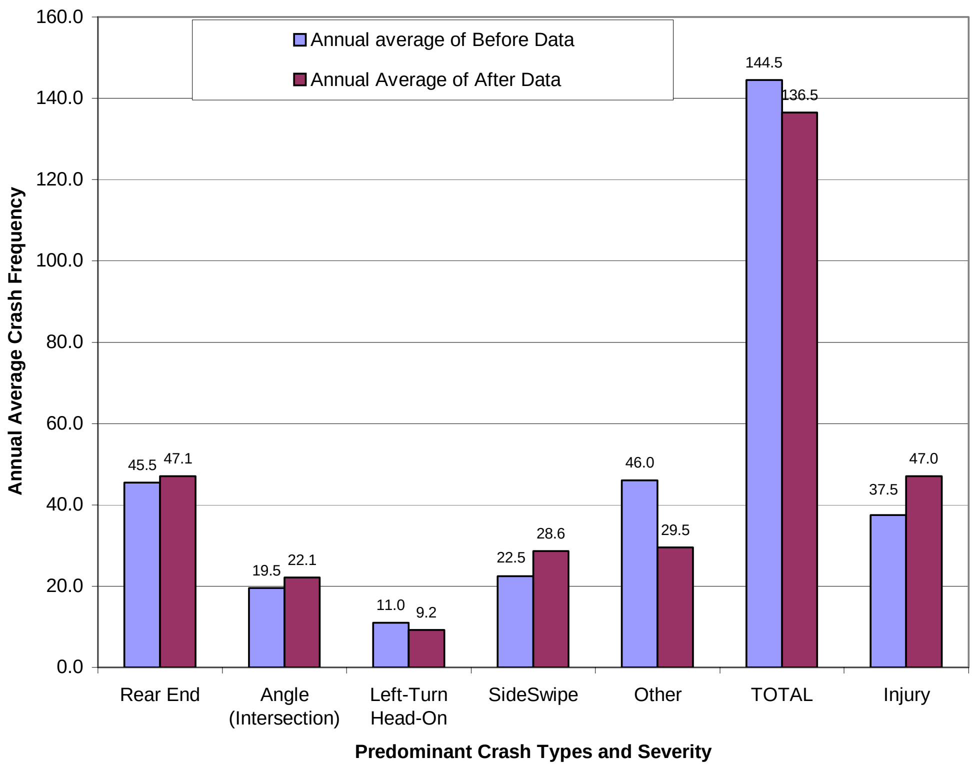


Figure 12. Comparison of Crash Types for the Grand River Avenue Corridor

5.1.2 Wyoming Road Corridor – City of Detroit

At all of the intersections along the Wyoming Road corridor, reductions in total crashes were observed after the implementation of the safety treatments, as shown in Figure 13.

The 'after' periods used in this evaluation are as follows:

- Traffic crash data for the 'after' period was analyzed from December 2001 to August 2002 (9 months of data) for the Wyoming Road intersections at Lyndon Road, Puritan Road and Schoolcraft Road.

- Traffic crash data for the ‘after’ period was analyzed from November 2001 to August 2002 (10 months of data) for the intersection of Wyoming Road and Curtis Road.
- Traffic crash data for the ‘after’ period was analyzed from March 2002 to August 2002 (6 months of data) for intersection of Wyoming Road and Seven Mile Road.

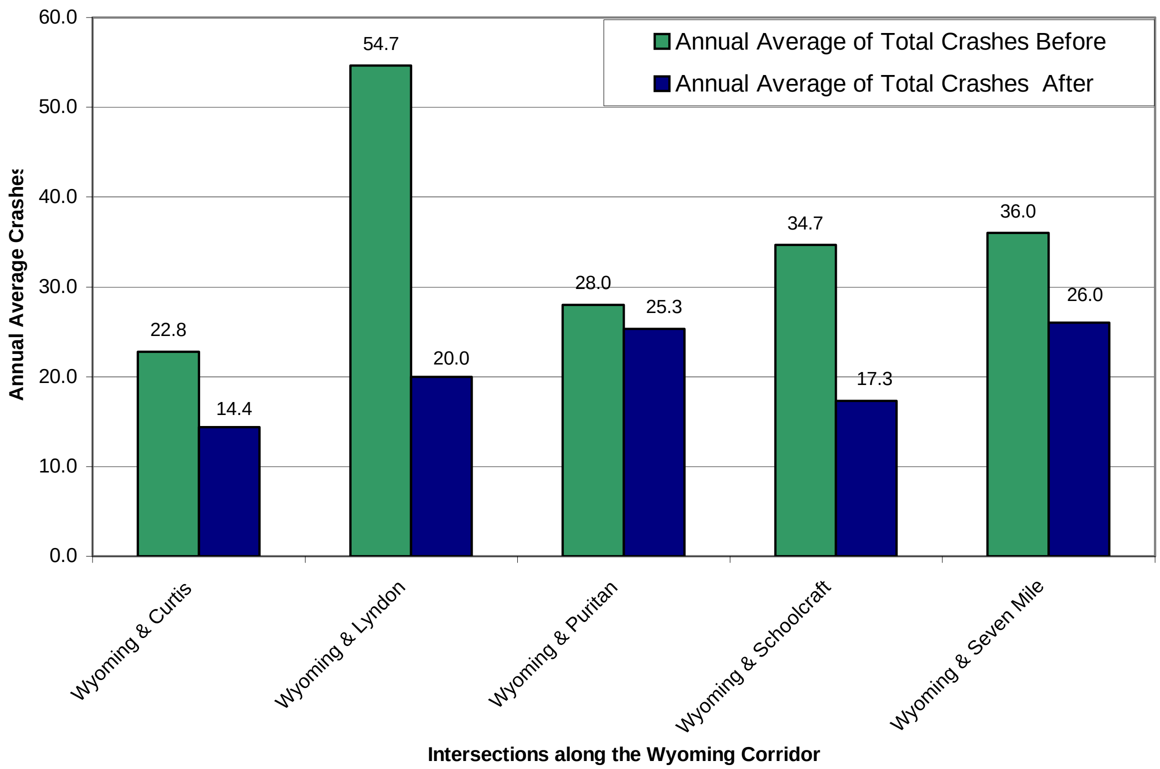


Figure 13. Comparison of Total Crashes for the Wyoming Road Corridor Intersections

The safety treatments installed were intended to reduce angle, left-turn head-on and injury crashes.

At a corridor level, the percent reductions for the targeted crash types, as shown in Figure 14 indicate that the safety treatments had a positive effect in improving safety.

- Angle crashes reduced by 52 percent
- Left-turn head-on crashes reduced by 76 percent
- Injury crashes reduced by 56 percent
- Total crashes reduced by 41 percent

Details of the 'before and after' crash analysis, including bar charts showing the crash frequencies for angle, left-turn head-on and injury crashes for each of the Wyoming Road corridor intersections are included in Appendix IV.

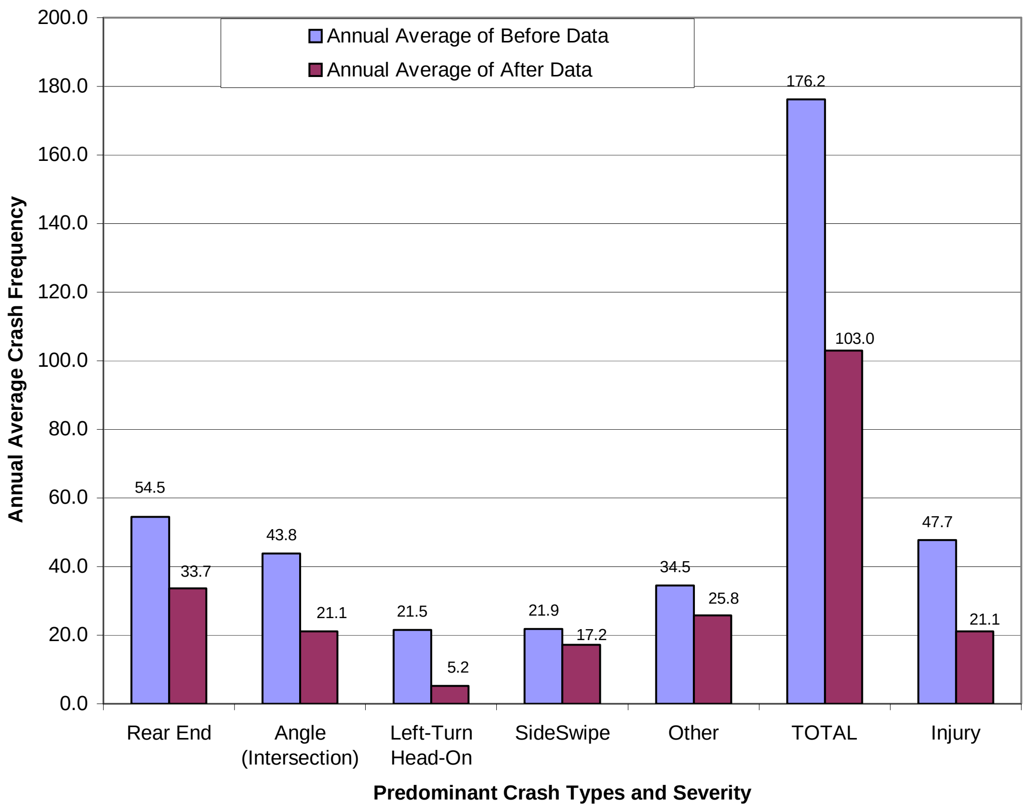


Figure 14. Comparison of Crash Types for the Wyoming Road Corridor

5.1.4 *Burton Street Corridor – City of Grand Rapids*

The total crashes were reduced at all of the Burton Street corridor intersections 'after' the implementation of the safety treatments, as shown in Figure 15.

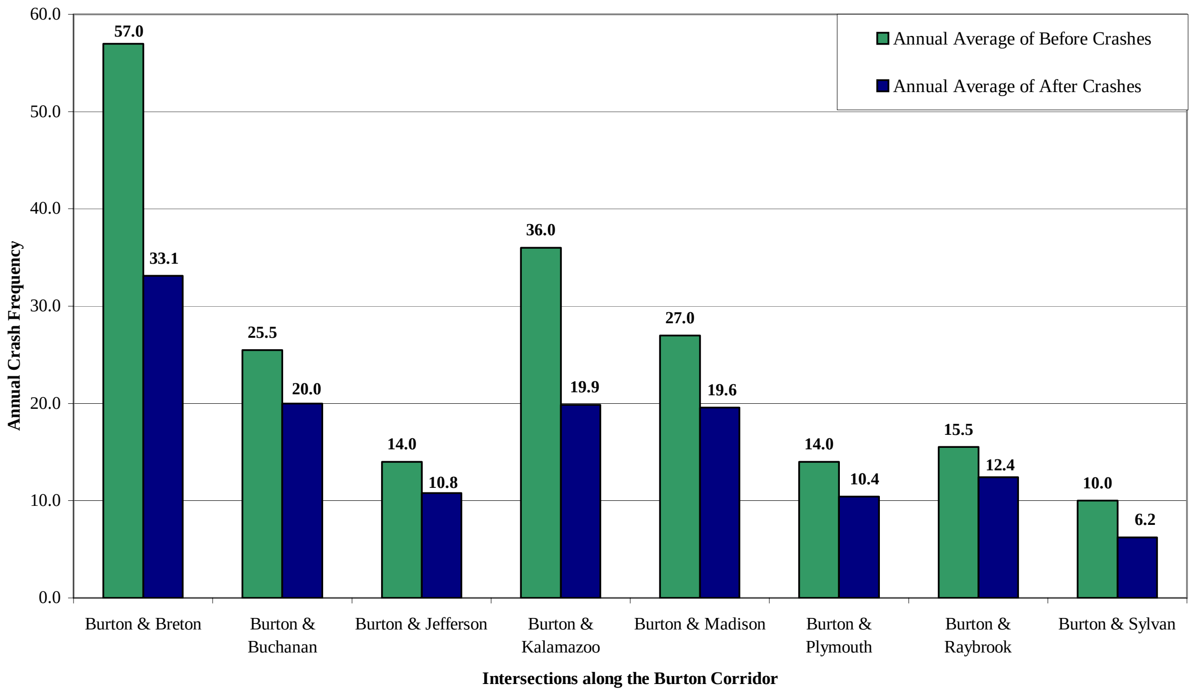


Figure 15. Comparison of Total Crashes for the Burton Street Corridor Intersections

The safety treatments implemented at the Burton Street corridor intersections were not implemented at the same time. Some of the intersections were improved in February 2000, while others were improved in March 2000. The 'after' periods used in this evaluation are as follows:

- Burton Street intersections at Plymouth, Madison, Jefferson and Buchanan: March 2000 to August 2002 (30 months of 'after' data).
- Burton Street intersections at Raybrook, Breton, Sylvan and Kalamazoo: April 2000 to August 2002 (29 months of 'after' data).

The safety treatments installed were intended to reduce angle, left-turn head-on and injury crashes. Figure 16 shows the 'before' and 'after' crash frequency for total and injury crashes, as well as for all the crash types for the Burton Street corridor intersections. Details of the 'before and after' crash analysis, including bar charts showing the crash frequencies for angle, left-turn head-on and injury crashes for each of the Burton Street corridor intersections are included in Appendix V.

At a corridor level, the percent reductions for the targeted crash types, as shown in Figure 16 indicate that the safety treatments had a positive effect in improving safety.

- Angle crashes reduced by 62 percent
- Left-turn head-on crashes reduced by 58 percent
- Injury crashes reduced by 44 percent
- Total crashes reduced by 33 percent

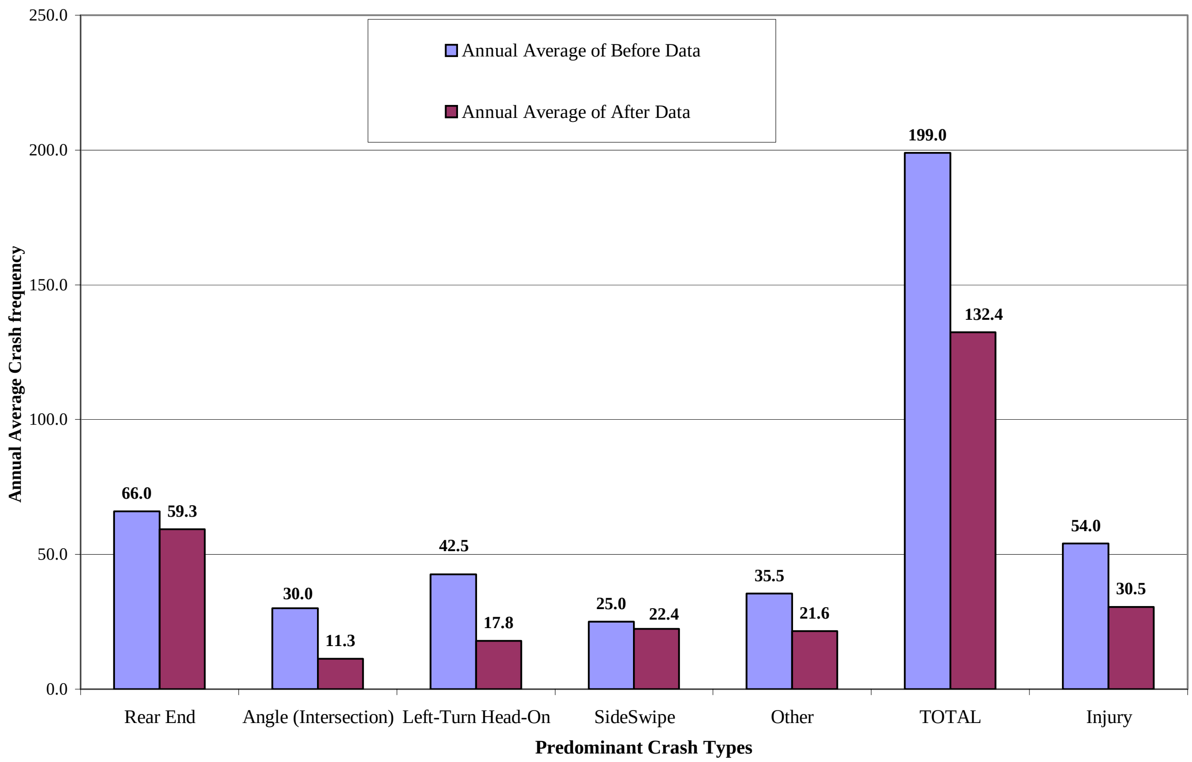


Figure 16. Comparison of Crash Types for the Burton Street Corridor

5.1.3 Division Avenue Corridor – City of Grand Rapids

At most of the Division Avenue corridor intersections, a reduction in total crashes was observed after the safety treatments were implemented as shown in Figure 17. However, a slight increase in total crashes was observed at the Division Avenue intersections at Cherry, Franklin and Cottage Grove. The implementation of the safety improvements for the intersections along the corridor occurred at different times. The 'after' periods used in this evaluation are as follows:

- Division Avenue intersections at Cherry Street and Delaware Street: January 2001 to August 2002 (20 months of 'after' data)
- Division Avenue and Wealthy Street intersection: November and December 1999 and January 2001 to August 2002. (22 months of 'after' data)
- Division Avenue and Franklin Street intersection: August 1998 to December 1999 and January 2001 to August 2002. (37 months of 'after' data)
- Division Avenue and Hall Street intersection: November 1998 to December 1999 and January 2001 to August 2002. (34 months of 'after' data)
- Division Avenue and Cottage Grove intersection: March 1999 to August 2002. (42 months of 'after' data)
- Division Avenue and Weston Street intersection: July 1999 to December 1999 and January 2001 to August 2002. (26 months of 'after' data)
- Division Avenue and Oakes Street intersection: September 1999 to December 1999 and January 2001 to August 2002. (24 months of 'after' data)

Traffic crash data for all of the Division Avenue corridor intersections was analyzed until August 2002 for the 'after' period, which resulted in a range of 20 months to 42 months of 'after' data used in the evaluation study. It is important to note that the Division Avenue corridor from Hall Street to Weston Street was also used as a detour route for US-131 during the year 2000. At these seven intersections the crashes for the year 2000 were not included in the effectiveness evaluation. The detour created increased traffic volumes, thereby changing the traffic characteristics at the intersections that were part of the detour route.

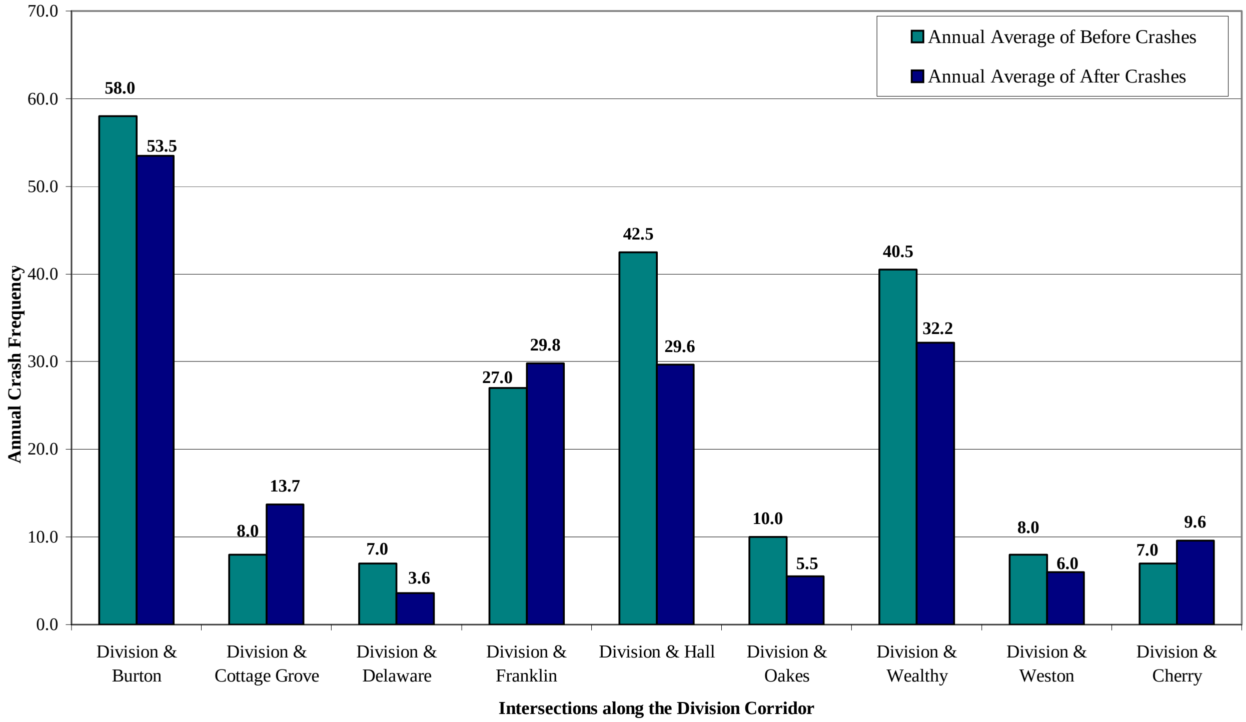


Figure 17. Comparison of Total Crashes for the Division Avenue Corridor Intersections

The safety treatments installed were intended to reduce angle, left-turn head-on and injury crashes. Details of the 'before and after' crash analysis, including bar charts showing the crash frequencies for the angle, left-turn head-on and injury crash types for each of the Division Avenue corridor intersections are included in Appendix VI.

At a corridor level, the following percent reductions for the targeted crash types, as shown in Figure 18 indicate that the safety treatments had a positive effect in improving safety.

- Angle crashes reduced by 39 percent
- Left-turn head-on crashes reduced by 58 percent
- Injury crashes reduced by 38 percent
- Total Crashes reduced by 12 percent

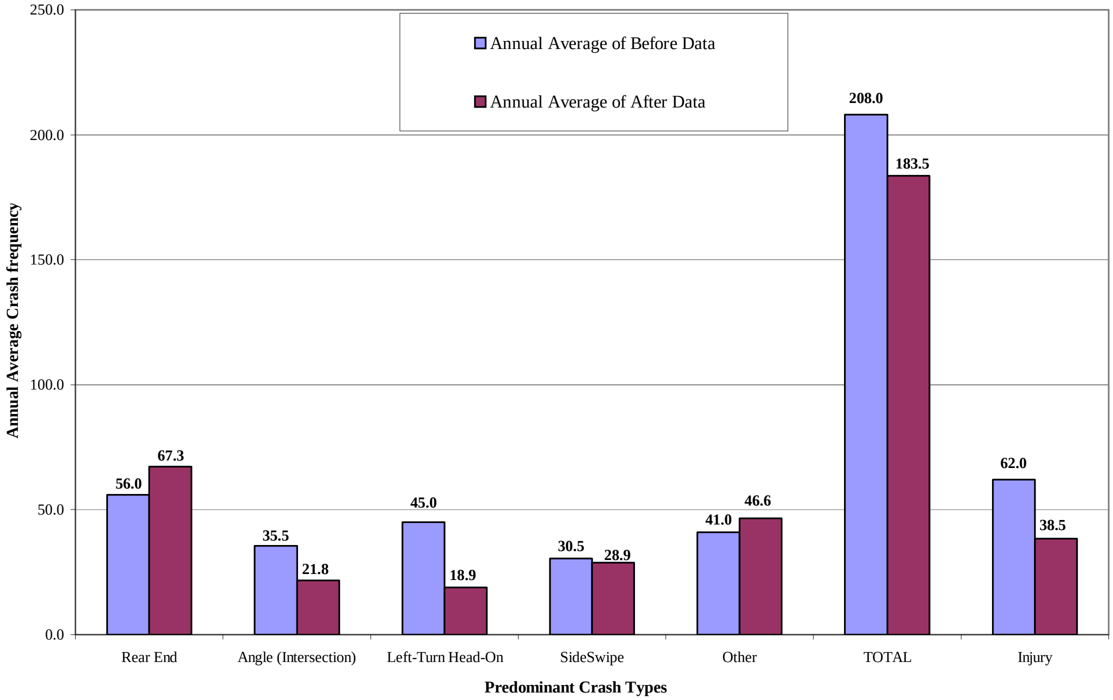


Figure 18. Comparison of Crash Types for the Division Avenue Corridor

5.1.4 Eastern Avenue Corridor – City of Grand Rapids

All of the intersections along the Eastern Avenue corridor, with the exceptions of the intersections at Wealthy Street, Hall Street and Oakdale Street, show a reduction in total crashes 'after' the safety improvements were implemented, as shown in Figure 19. At the intersections along the Eastern Avenue corridor, the safety countermeasures were implemented at different times. The 'after' periods used in this evaluation are as follows:

- Traffic crash data for the 'after' period was analyzed from January 2001 to August 2002 (20 months of data) for the intersections of Eastern Avenue with Franklin Street, Wealthy Street, Cherry Street, Alger Street and Lake Drive.
- The 'after' crash data was analyzed from February 2000 to August 2002 (31 months of data) for the intersections of Eastern Avenue with Oakdale Street and Hall Street.
- The 'after' crash data was analyzed from May 2001 to August 2002 (16 months of data) for the intersection of Eastern Avenue and Burton Street.

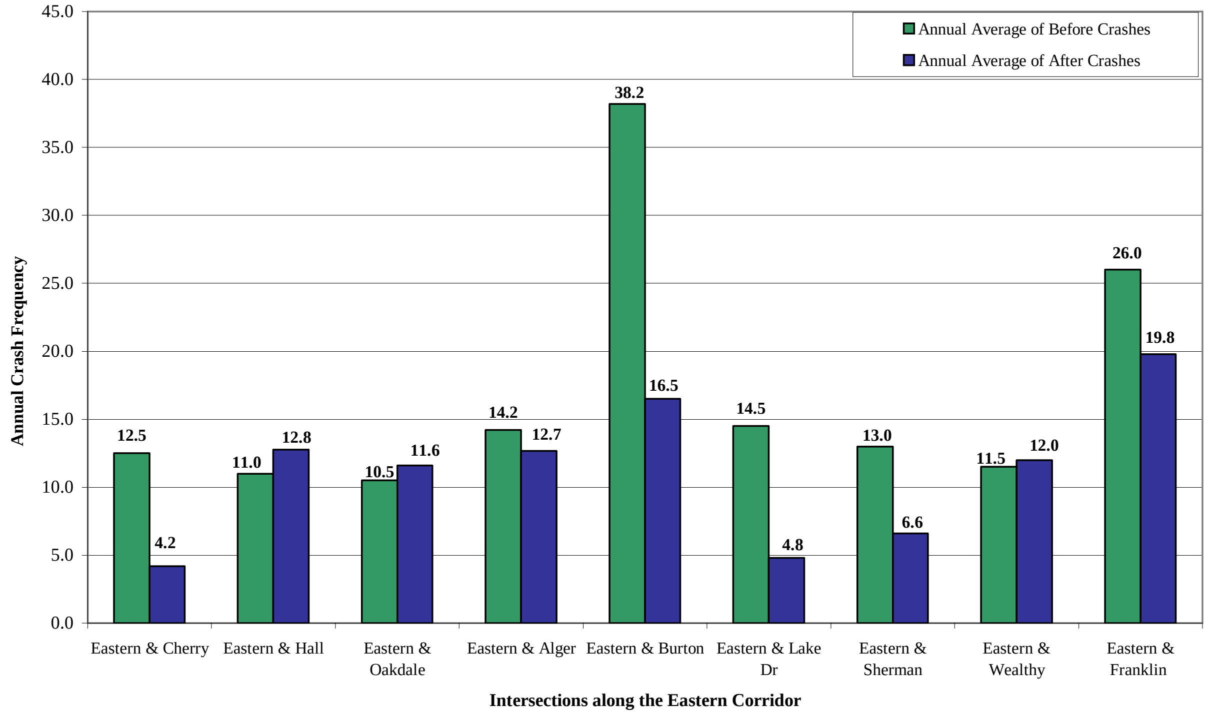


Figure 19. Comparison of Total Crashes for the Eastern Avenue Corridor Intersections

The safety treatments installed were intended to reduce angle, left-turn head-on and injury crashes. Details of the 'before and after' crash analysis, including bar charts showing the crash frequencies for the targeted crash types for each of the Eastern Avenue corridor intersections are included in Appendix VII.

At a corridor level, the percent reductions as shown in Figure 20 for the targeted crash types, indicate that the safety treatments implemented at the intersections were effective in reducing the following:

- Angle crashes reduced by 71 percent
- Left-turn head-on crashes reduced by 54 percent
- Injury crashes reduced by 59 percent
- Total crashes reduced by 33 percent

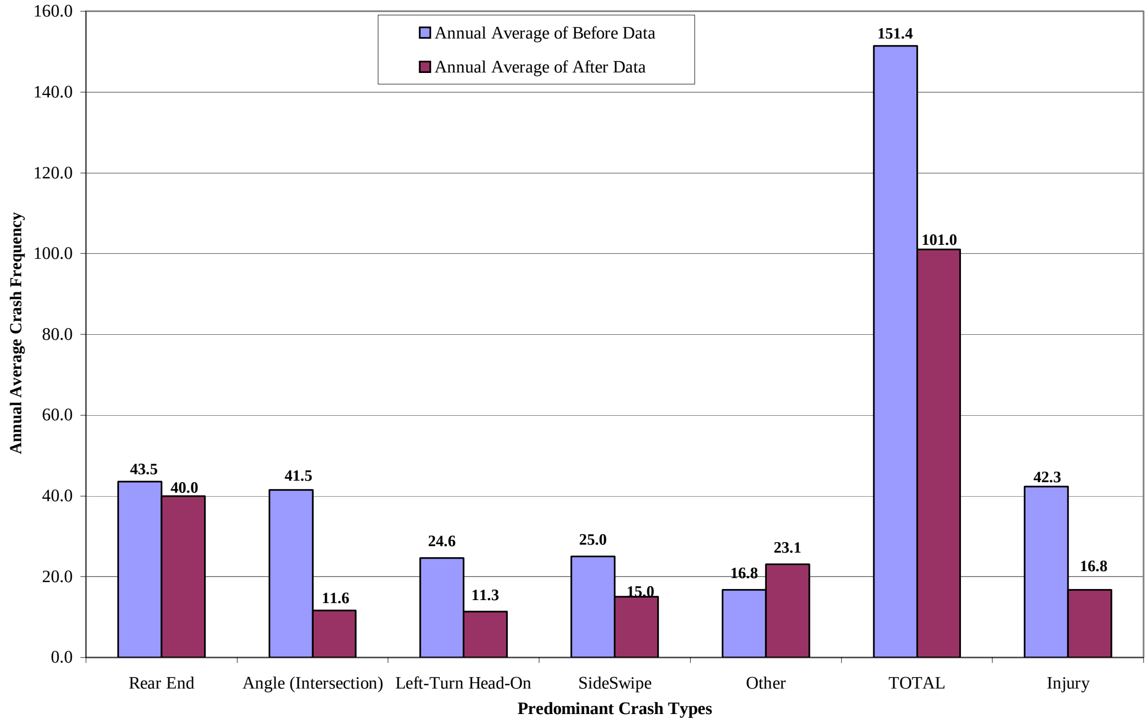


Figure 20. Comparison of Crash Types for the Eastern Avenue Corridor

5.2 Results of Traffic Crash Analyses for the Isolated Intersections

For the isolated intersection locations, charts providing the average annual crashes for total crashes, injury crashes and by each crash type for the 'before' and 'after' periods are provided. In addition, a yearly trend analysis is also provided for the intersections where over four years of 'after' crash data has been accumulated. The summaries for the isolated intersections in the City of Detroit and Grand Rapids are included in Appendix VIII.

The following is a brief description of the crash and injury experiences at the isolated intersections.

5.2.1 *Seven Mile Road and John R Road, City of Detroit*

The three-year 'before' data (Figure 21) shows a slight decrease in the annual trend for the 'before' period for both the total and injury crashes. The five-year 'after' period data essentially shows no trend, except that the annual crashes are less than the 'before' period. The middle two years of ‘after’ data (1998-1999 and 1999-2000) in Figure 21 shows lower crashes as compared to the first and fourth year (1997-1998 and 2000-2001) of data. In the fifth year, there was also a significant decrease in the number of crashes, which is the lowest of all the years in the ‘after’ period.

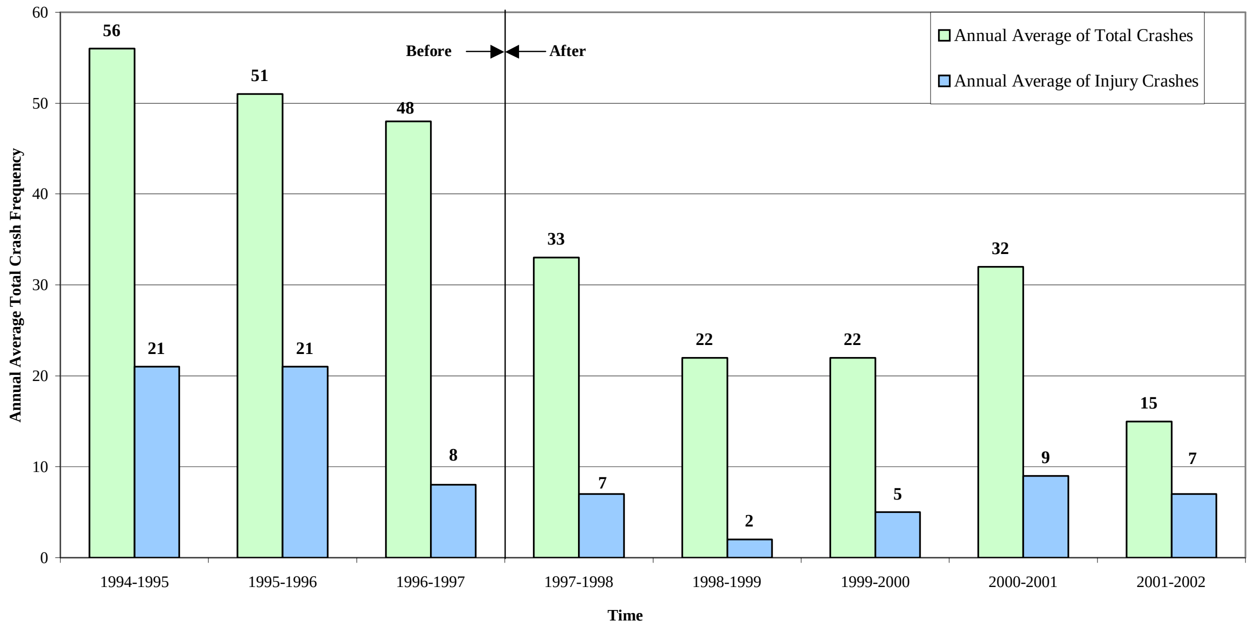


Figure 21. Yearly Trend Analysis for Total and Injury Crashes for the Intersection of Seven Mile Road and John R Road

Figure 22 shows the reductions in targeted crash types including angle, left-turn head-on and injury crashes during the ‘after’ period for the intersection of Seven Mile Road and John R Road. This figure shows that total crashes were reduced by 51 percent, while injury crashes were reduced by 64 percent.

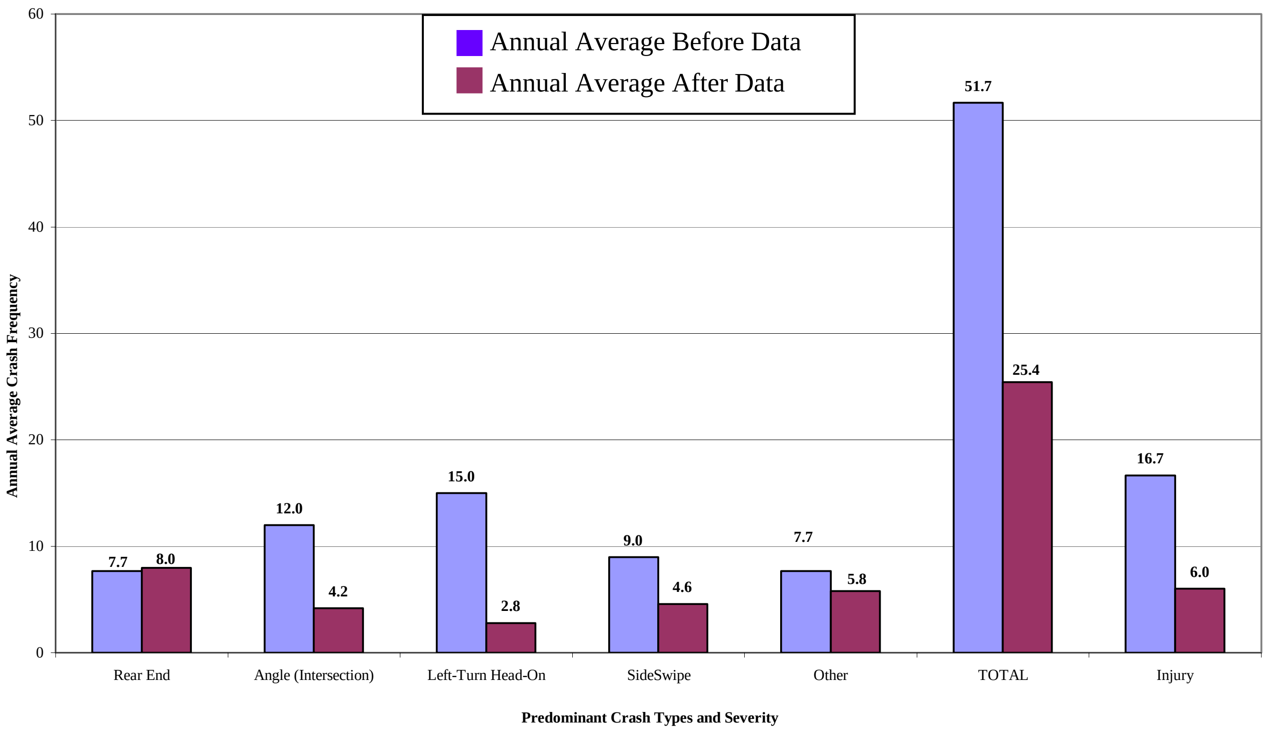


Figure 22. Comparison of 'Before and After' Crashes for the Intersection of Seven Mile Road and John R Road

5.2.2 Seven Mile Road and Ryan Road, City of Detroit

The trend analysis for the 'before' period (Figure 23) shows an increase in the total crashes, over the three-year study period while the injury crashes remained more or less the same. In the 'after' period, the total and injury crashes significantly decreased. However, the total crashes increased slightly from the first year of the 'after' period (1997-1998) to the second year (1998-1999). The crash experience over the next three years remained essentially constant followed by an even further reduction in the fifth year. A similar trend has been observed for the injury crashes during the 'after' period. The targeted crash types including angle, left-turn head-on and injury crashes reduced significantly in the 'after' period, as shown in Figure 24. This figure shows that total crashes were reduced by 54 percent, while injury crashes were reduced by 72 percent.

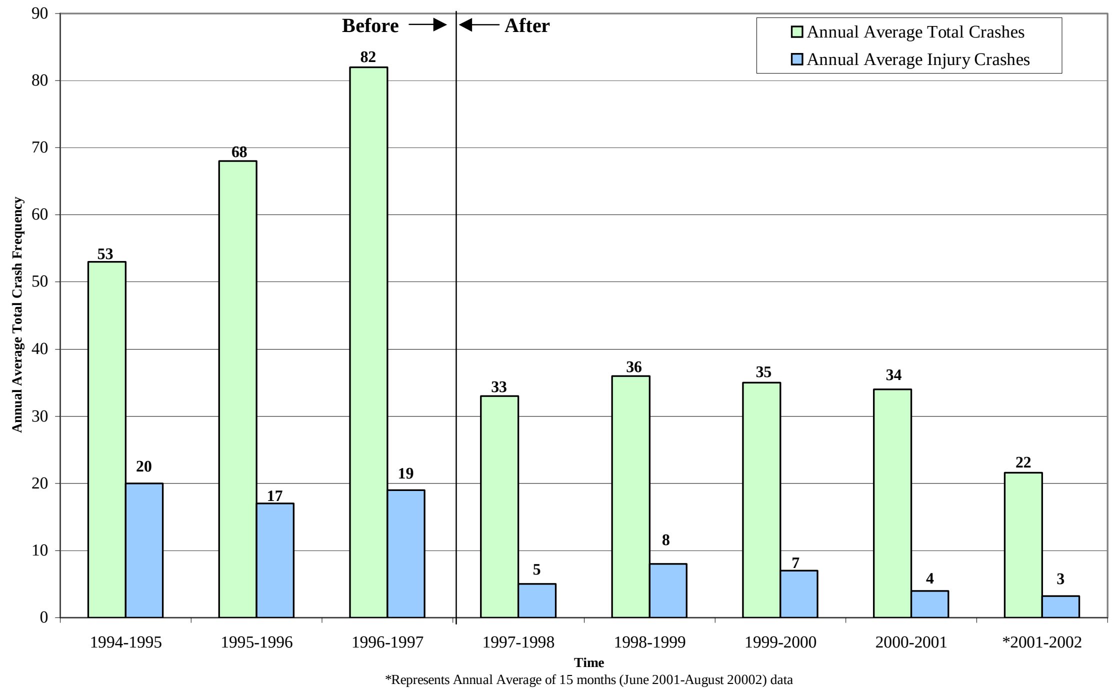


Figure 23. Yearly Trend Analysis for Total and Injury Crashes for the Intersection of Seven Mile Road and Ryan Road

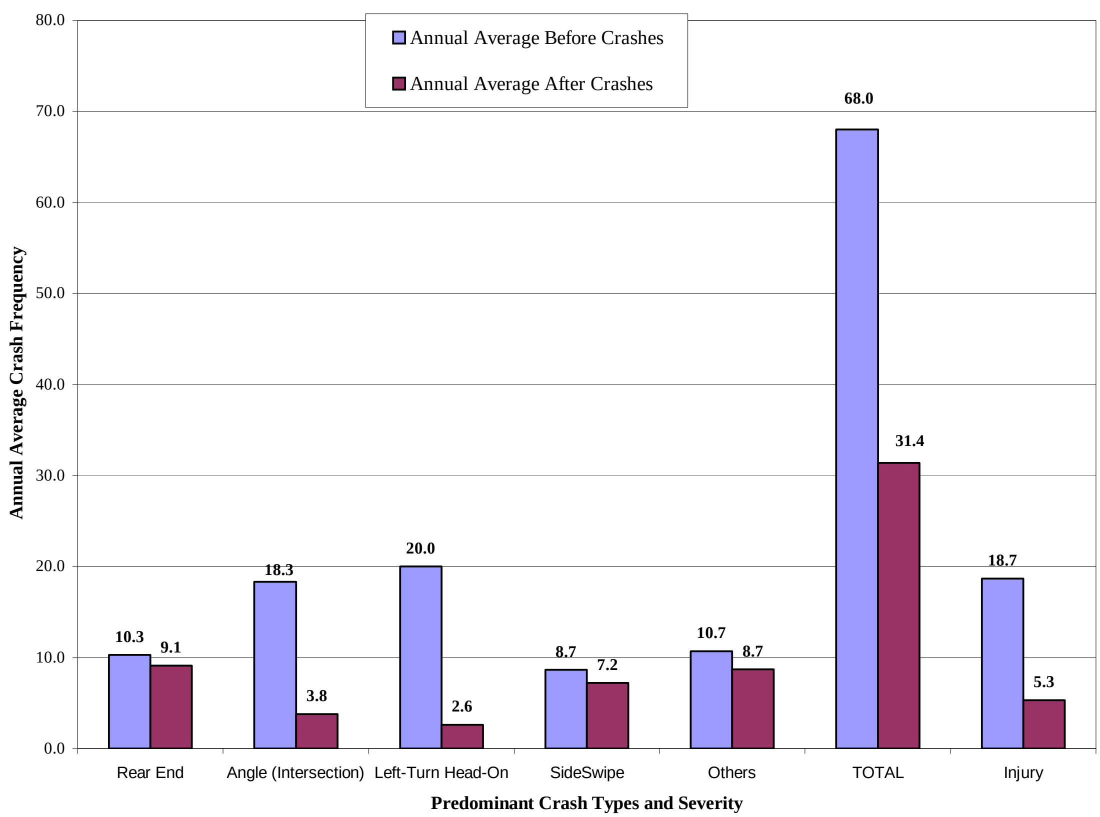
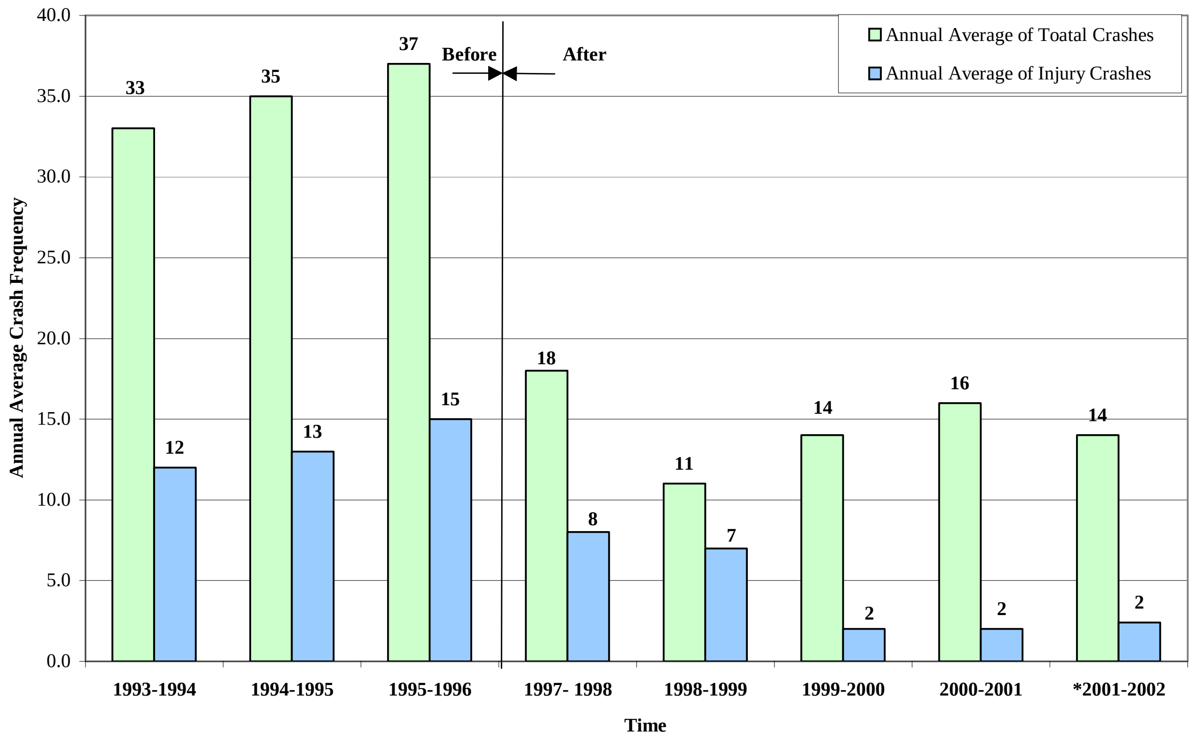


Figure 24. Comparison of 'Before and After' Crashes for the Intersection of Seven Mile Road and Ryan Road

5.2.3 Hubbell Road and Puritan Road, City of Detroit

The trend analysis for the intersection of Hubbell Road and Puritan Road (Figure 25) shows an increasing trend in the total and injury crashes during the 'before' period. Although the total and injury crash frequencies showed a reduction in the 'after' period, there is no predominant trend in the five years of 'after' data for total crashes. The total crashes decreased from the first year to the second of the 'after' period, and then again increased slightly till the fourth year and finally decreased from the fourth year to the fifth year. There was however, a drop in the injury crashes for the years 1999 to 2001. Figure 26 shows the crash frequencies for the 'before' and 'after' periods for each crash and injury type. From this graph, it is apparent that the crash frequencies for the targeted crash types including angle, left-turn head-on and injury crashes have been reduced. Total crashes were reduced by 58 percent, while injury crashes were reduced by 68 percent.



*Represents annual average of 10 months (November 2001-August 2002) data

Figure 25. Yearly Trend Analysis for Total and Injury Crashes for the Intersection of Hubbell Road and Puritan Road

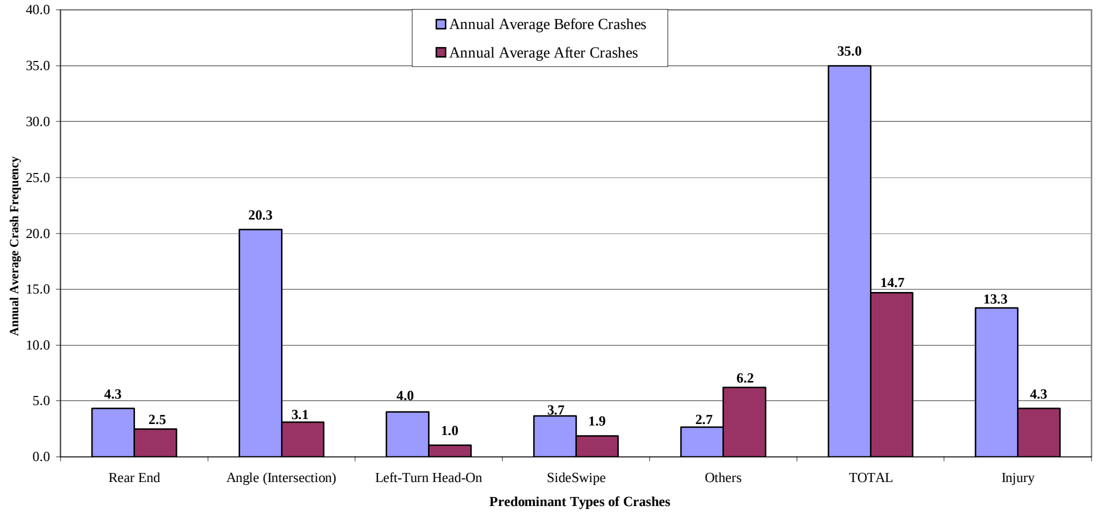


Figure 26. Comparison of 'Before and After' Crashes for the Intersection of Hubbell Road and Puritan Road

5.2.4 Schoolcraft Road and Evergreen Road, City of Detroit

The trend of annual traffic crashes for the three-year 'before' period, as shown in Figure 27, indicates that the total crashes decreased from the first to the second year (1993-1994 to 1994-1995) and again increased from the second to the third year (1994-1995 to 1995-1996). The injury crashes show the same trend during the three-year 'before' period. The crash frequencies in the 'after' period indicate a reduction in crashes as compared to the 'before' period, and also shows a decreasing trend for the first three years (1998 to 2001) and then an increase is observed from the third to the fourth year (2000-2001 to 2001-2002).

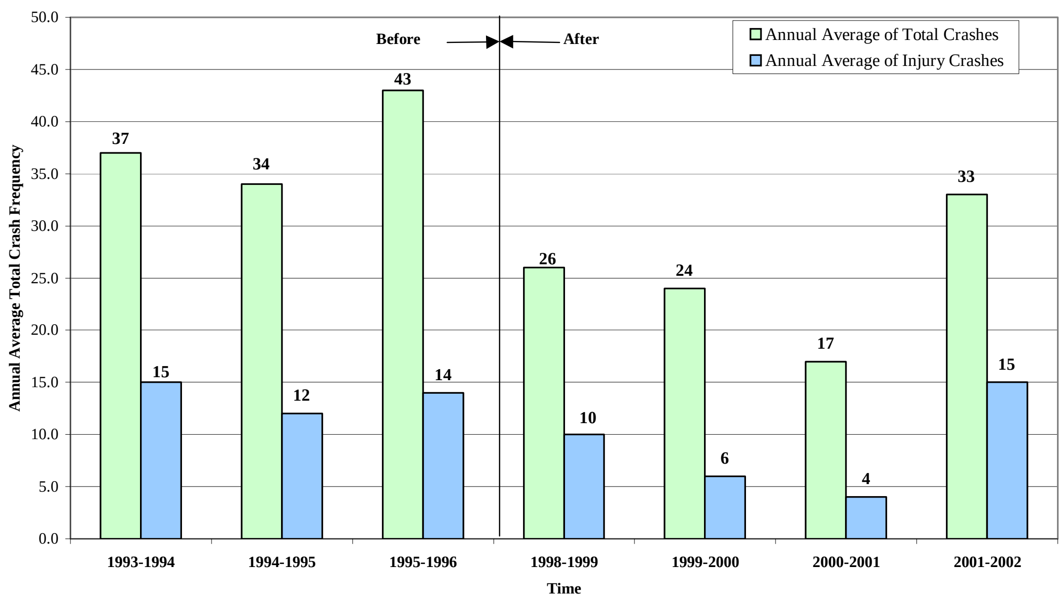


Figure 27. Yearly Trend Analysis for Total and Injury Crashes for the Intersection of Schoolcraft Road and Evergreen Road

The comparison of the annual average crash frequencies by type (Figure 28) indicate that all the crash types experienced reductions, including the targeted crash types such as angle, left-turn head-on and injury crashes. Total crashes were reduced by 34 percent, while injury crashes were reduced by 40 percent.

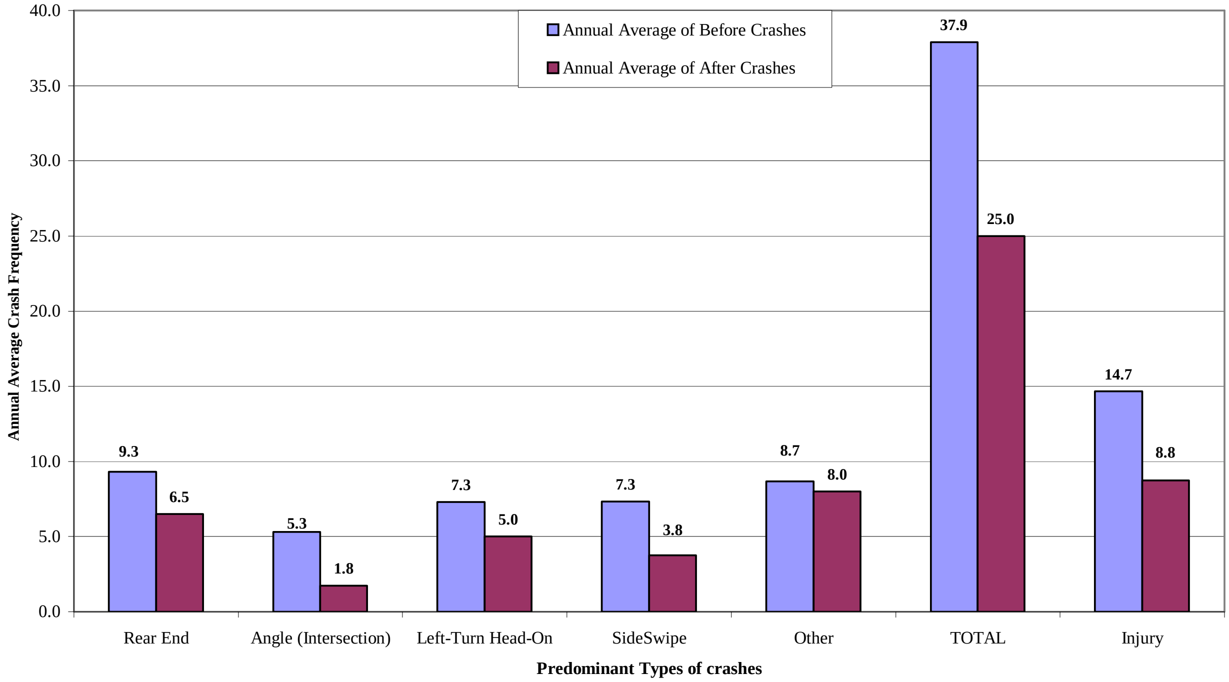


Figure 28. Comparison of 'Before and After' Crashes for the Intersection of Schoolcraft Road and Evergreen Road

5.2.5 *Leonard Street and College Avenue, City of Grand Rapids*

The total and injury crashes at the Leonard Street and College Avenue intersection showed a decreasing trend in the 'before' period, which also continued to decrease in the 'after' period (Figure 29). However, in the 'after' period, the total crashes for all four years remained much lower than in the 'before' period. The total crashes show a decreasing trend over the four year 'after' period with same number of crashes for the middle two years. The injury crashes also show a decreasing trend over the four-year 'after' period.

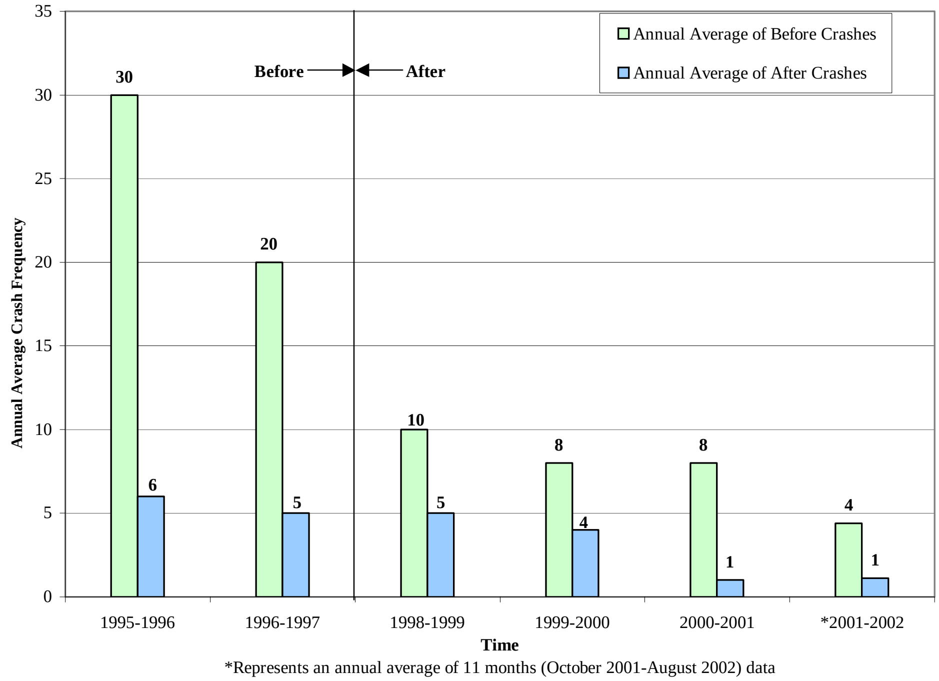


Figure 29. Yearly Trend Analysis for Total and Injury Crashes for the Intersection of Leonard Street and College Avenue

Figure 30 shows the reduction in crashes for all the crash types at the Leonard Street and College Avenue intersection. The largest reductions were observed for targeted crash types including angle, left-turn head-on and injury crashes. Total crashes were reduced by 69 percent, while injury crashes were reduced by 49 percent.

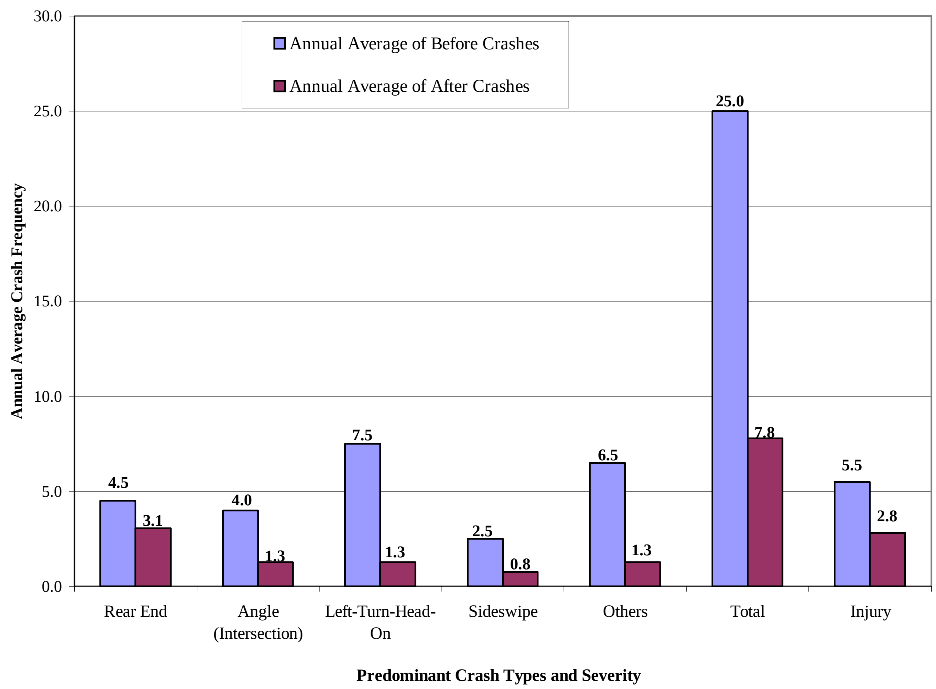


Figure 30. Comparison of 'Before and After' Crashes for the Intersection of Leonard Street and College Avenue

5.2.6 Cadieux Avenue and I-94 Service Drives, City of Detroit

Figure 31 shows a reduction in angle, total and injury crashes, as well as rear-end crashes at the Cadieux Avenue and I-94 Service Drive intersections. Total crashes were reduced by 44 percent, while injury crashes were reduced by 8 percent.

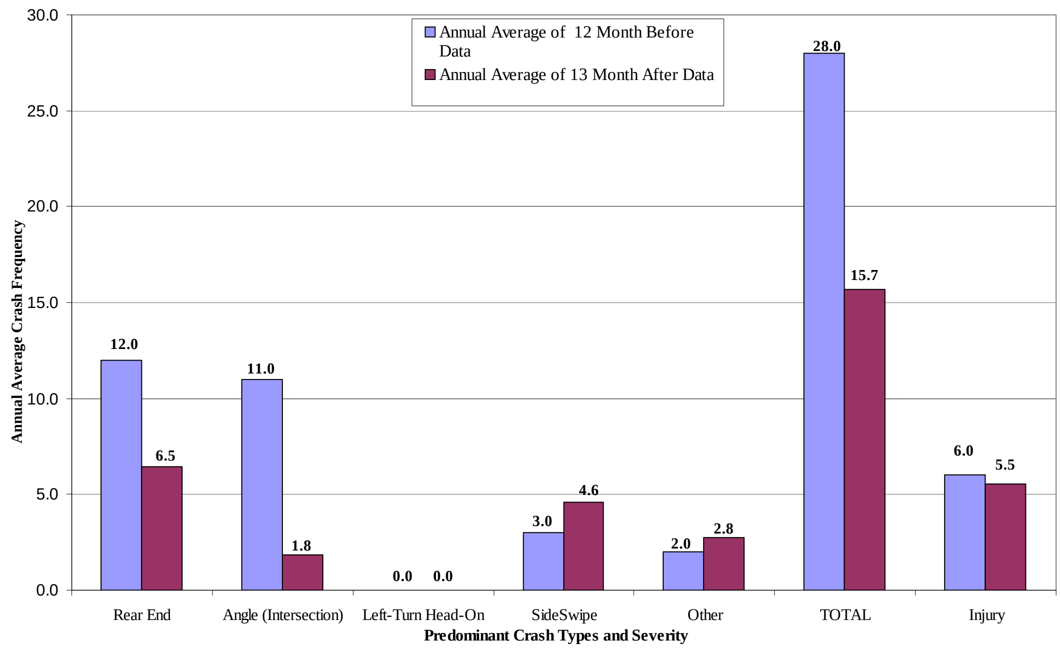


Figure 31. Comparison of 'Before and After' Crashes for the Intersection of Cadieux Avenue and I-94 Service Drives

5.2.7 Davison Avenue and Dexter Road, City of Detroit

At the Davison Avenue and Dexter Road intersection a slight decrease in angle crashes and an increase in total and injury crashes in the 'after' period was observed, as shown in Figure 32.

At this intersection, many countermeasures were proposed, such as installing exclusive left-turn lanes, increasing the length of the all-red interval, increasing the signal heads to 12-inch diameters and others. However, the only improvements included increasing the signal lens size, installing left-turn case signs, and installing pedestrian signals. All of the recommended improvements were not installed, which may have impacted the crash experience at this intersection.

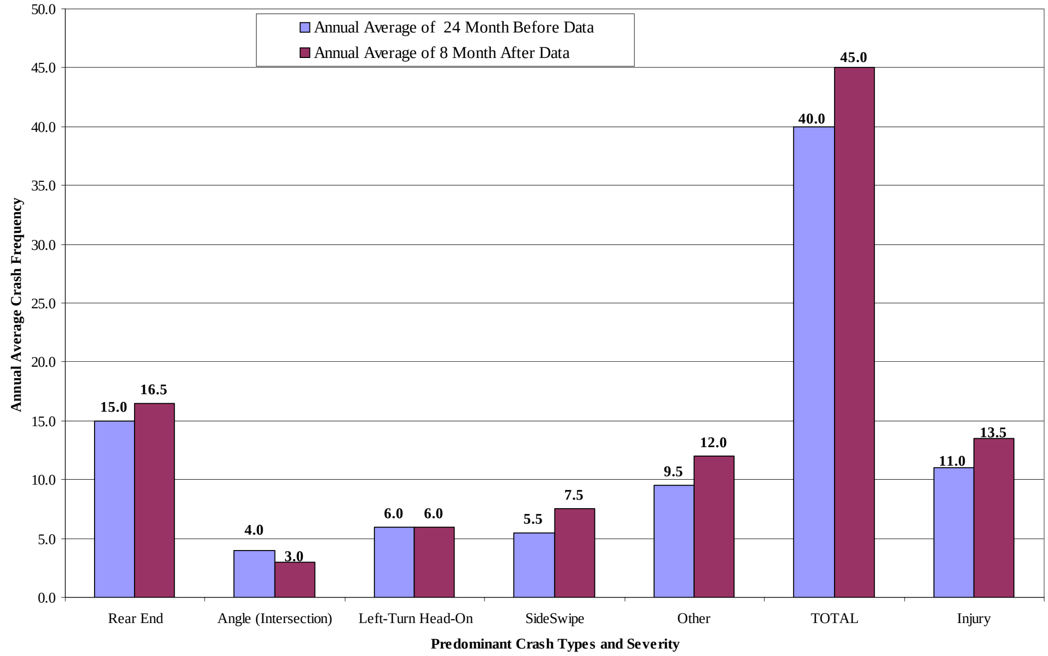


Figure 32. Comparison of 'Before and After' Crashes for the Intersection of Davison Avenue and Dexter Road

5.2.8 Harper Avenue and Cadieux Avenue, City of Detroit

At the Harper Avenue and Cadieux Avenue intersection, most of the crash types reduced in the 'after' period, as shown in Figure 33. The total crashes reduced by 26 percent and the injury crashes reduced by 26 percent as well.

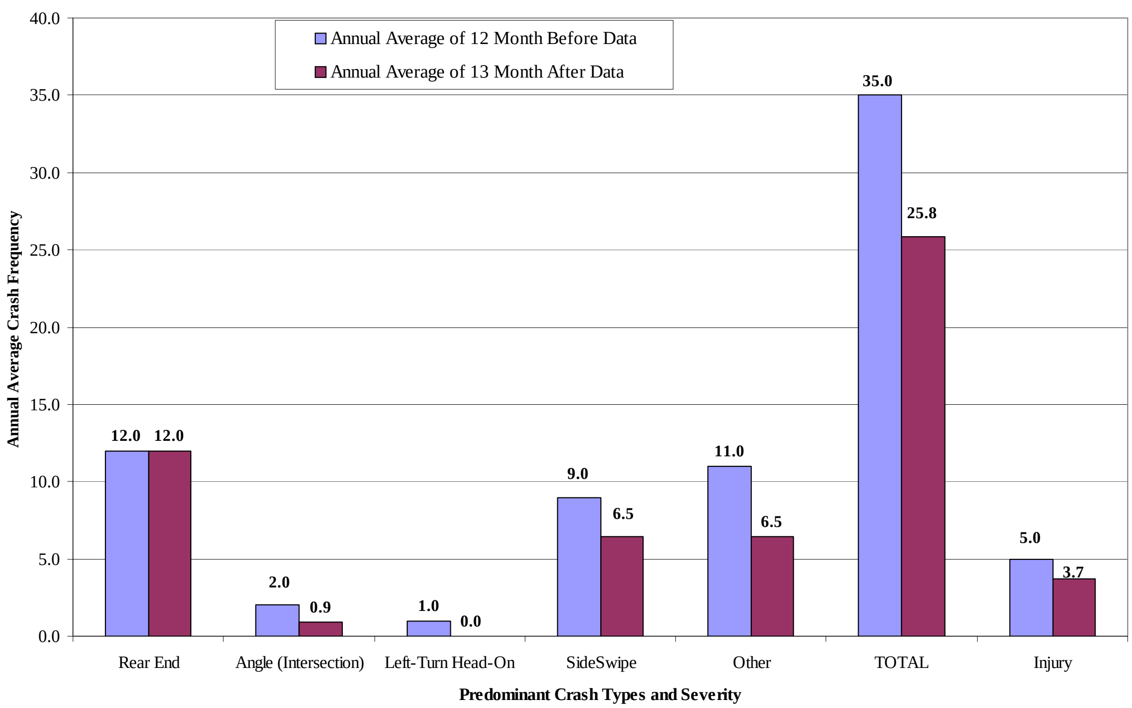


Figure 33. Comparison of 'Before and After' Crashes for the Intersection of Harper Avenue and Cadieux Avenue

5.2.9 *Harper Avenue and Dickerson Road, City of Detroit*

At the Harper Avenue and Dickerson Road intersection, angle, total and injury crashes reduced after the safety treatments were implemented. Total crashes were reduced by 10 percent, while injury crashes were reduced by 26 percent, as shown in Figure 34.

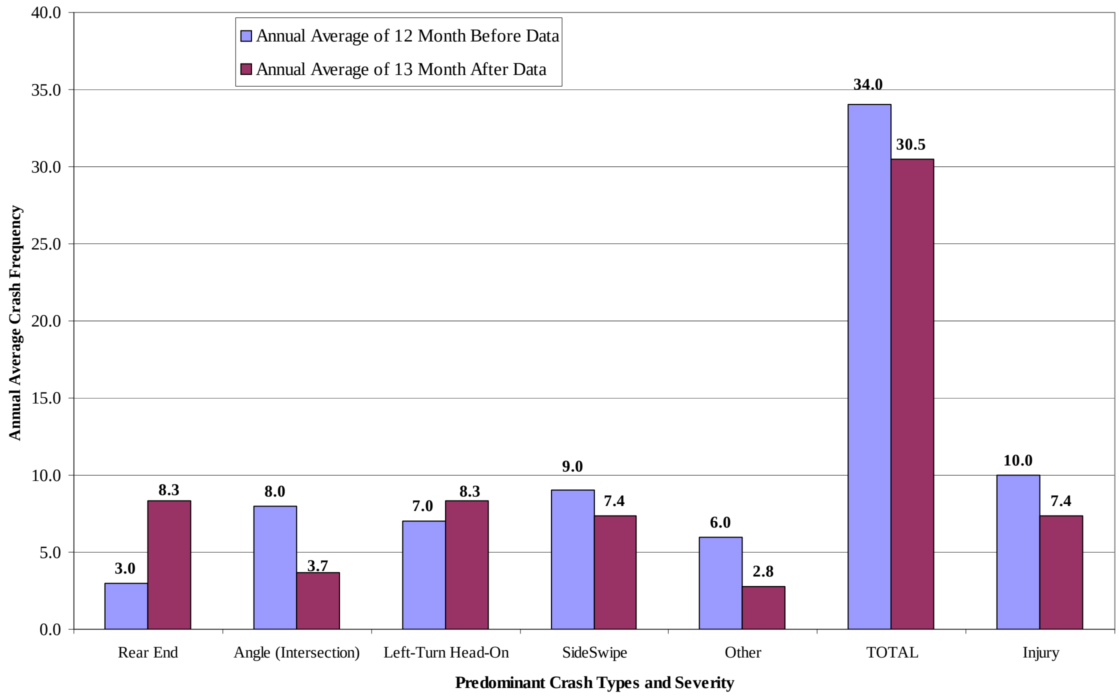


Figure 34. Comparison of 'Before and After' Crashes for the Intersection of Harper Avenue and Dickerson Road

5.2.10 *McNichols Road and Schaefer Highway, City of Detroit*

Total crashes at the McNichols Road and Schaefer Highway intersection remained the same in the 'before' and 'after' period. The implemented countermeasures included the installation of exclusive left-turn phases and low level traffic signals. Thus, left-turn head-on crashes were targeted, which reduced by 75 percent after implementation. The injury crashes also reduced by 43 percent in the 'after' period, as shown in Figure 35.

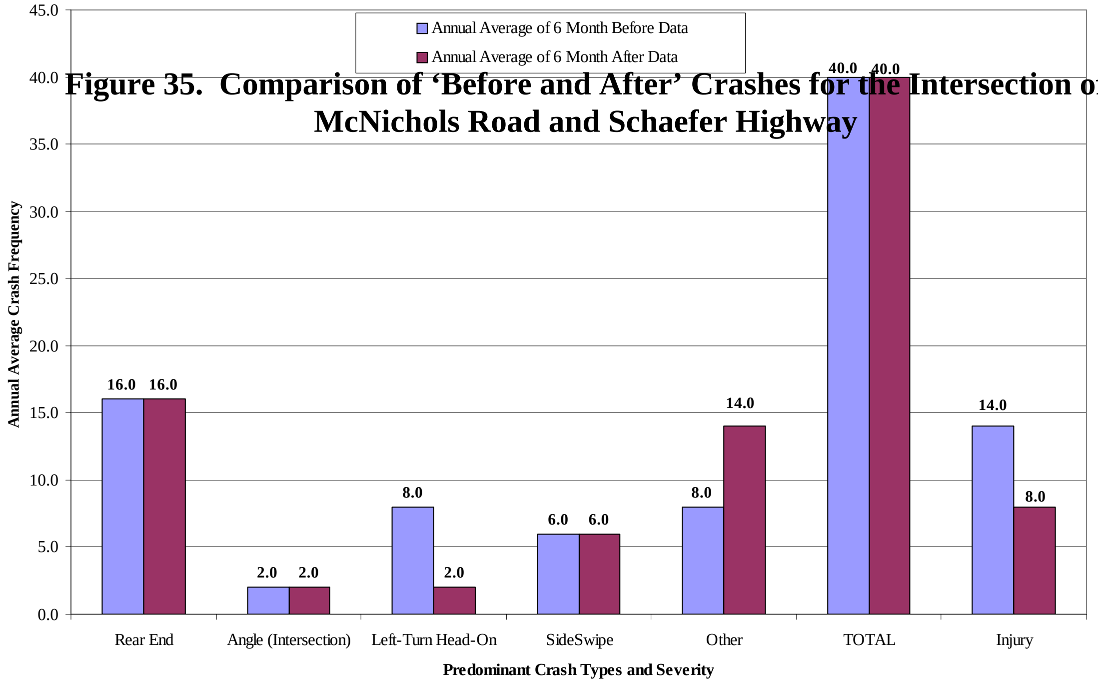


Figure 35. Comparison of 'Before and After' Crashes for the Intersection of McNichols Road and Schaefer Highway

5.2.11 Schaefer Highway and Seven Mile Road, City of Detroit

Figure 36 shows that the total crashes at the Schaefer Highway and Seven Mile Road intersection decreased from 37.5 crashes per year during the 'before' period to 18 crashes per year during the 'after' period. Also, the injury crashes at the intersection decreased from 10.5 crashes per year during the 'before' period to 4.5 crashes per year during the 'after' period. Decreases in all the crash types are observed in the 'after' period. Total crashes were reduced by 52 percent, while injury crashes were reduced by 57 percent.

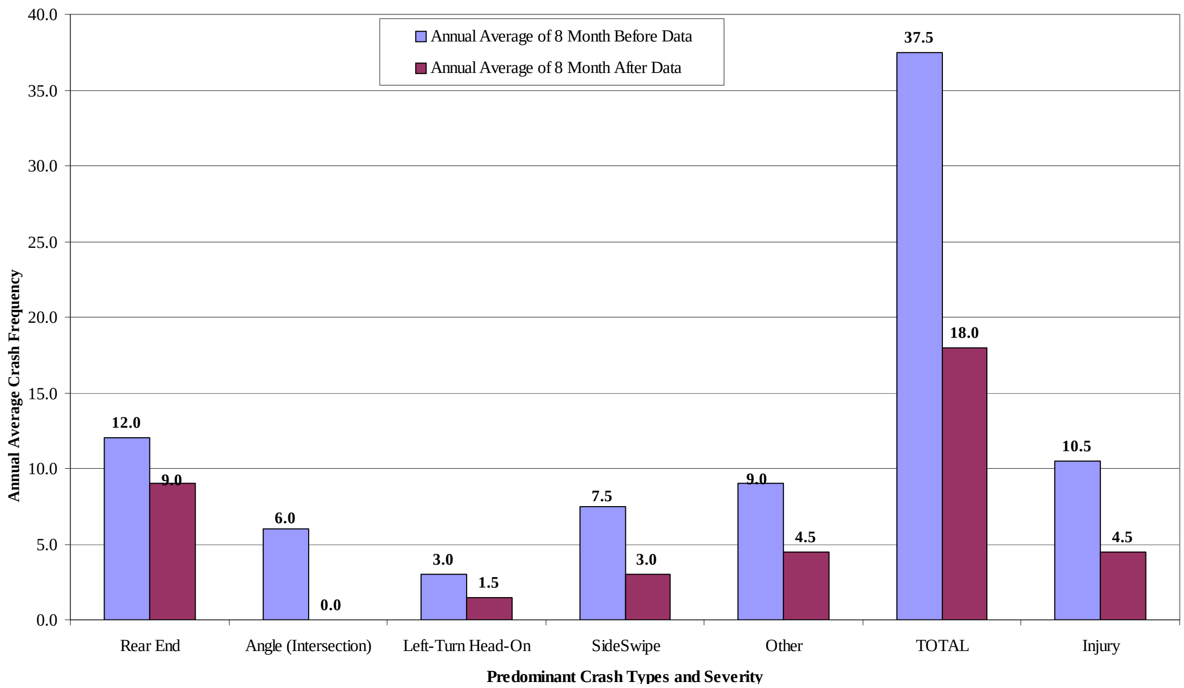


Figure 36. Comparison of 'Before and After' Crashes for the Intersection of Schaefer Highway and Seven Mile Road

6.0 EXPERIMENTAL PLANS AND STATISTICAL ANALYSES

The evaluation of safety treatments can be performed using a variety of experimental plans. Among them, the 'before and after' (B&A) (Figure 37) and the 'before and after with control' (B&A with control) (Figure 38) seem to be the most logical choices since multiple years of 'before' and 'after' data are available for many of the study sites.

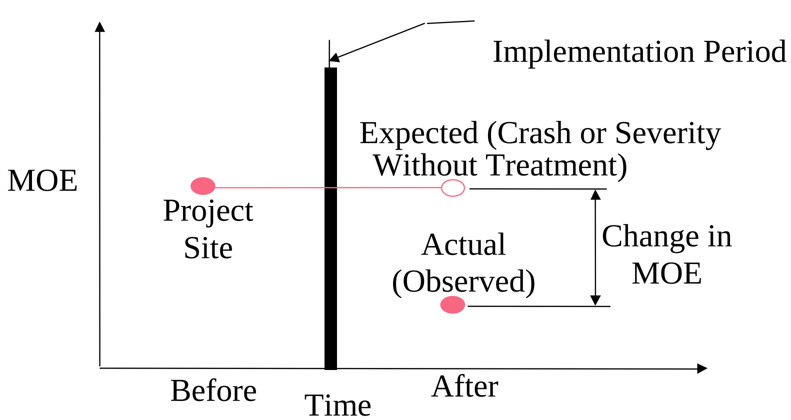


Figure 37. 'Before and After' Study Plan

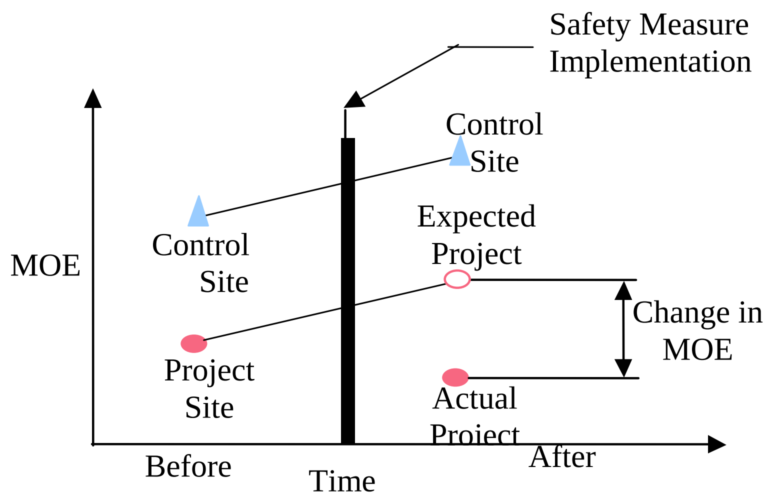


Figure 38. 'Before and After with Control' Study Plan

Conceptually, the B&A study assumes that the expected 'after' crash measures of effectiveness (MOEs) without improvement is the same as the 'before' crashes. Therefore, the change in the crash MOEs is measured as the difference in the 'before' and 'after' crash MOEs.

As a part of the RIDP, low cost improvements were implemented along the following corridors and isolated intersections:

1. Three major corridors in the City of Detroit
   - Woodward Avenue corridor including 33 signalized intersections
   - Grand River Avenue corridor including eight signalized intersections
   - Wyoming Road corridor including five signalized intersections
2. Three corridors in the City of Grand Rapids, Michigan
   - Burton Street corridor including eight signalized intersections
   - Division Avenue corridor including nine signalized intersections
   - Eastern Avenue corridor including nine signalized intersections
3. 11 isolated intersections in the City of Detroit, and 2 isolated intersections in the City of Grand Rapids

The effectiveness evaluation of the six corridors using the 'B&A study' were performed for the following reasons:

1. Each one of the six corridors included both high and low crash intersections.
2. Each one of the corridors is unique in its location within the metropolitan areas having different traffic patterns and possibly different driver characteristics.
3. The roadway geometry and land use along the corridors are also somewhat unique, creating different driver responses to various roadway and traffic control features.
4. The use of control corridors may introduce more errors than the use of 'B&A study' because it is difficult to identify a corridor with all its intersection characteristics identical to the study corridor intersection characteristics, and the overall evaluation might be faulty.
5. The use of both high and low crash locations along a corridor and multi-year crash data eliminates normal bias sometimes associated with high crash sites only.

The RIDP also includes 11 isolated intersections in the City of Detroit and two in the City of Grand Rapids. A 'B&A with control' type experimental plan is appropriate for isolated intersections in addition to simple B&A analyses. This plan will assist in identifying the true benefits and disbenefits associated with the installed low cost improvements at these locations.

6.1 Regression to the Mean

Some researchers believe that when countermeasures are installed at high crash locations, the results of a 'before and after' study are biased. According to Persaud and Hauer *(4)*, "the bias is caused by the erroneous assumption that the number of accidents on a system in the period before treatment is an unbiased estimate of what should be expected to occur on the system during an equivalent after period had the treatment not been applied". They also suggest that "systems with above-average accident numbers or rates in one period must be expected to show a decrease in a subsequent period even without treatment, and vice-versa" *(4)*. Thus, when simple 'before and after' comparisons are made, sometimes the safety treatments appear to be more effective than they actually are.

Regressions to the mean effects are typically observed at sites with very high values for crash frequencies, and are defined as "the tendency of the response variable to fluctuate about the true mean value"*(5)*. Thus, the decrease in the crash frequency during the 'after' period cannot be completely attributed to the improvements made at the site, unless proper care has been taken to guard against regression to the mean effects. However, this phenomenon does not necessarily occur at all high crash locations. If the crash trend over a multi-year period shows a continuous increasing or decreasing trend with little fluctuation in the crash frequency, the chances of the crash frequency changing during the 'after' period due to regression to the mean effect is low. However, if there is a sudden drop in the crash frequency after some improvements were made at a treatment site, and the observed crash frequencies over a period of time continues to follow the 'after period' trend and different from the multi-year trend observed during the 'before' improvement period, then this reduction **cannot** be attributed to the regression to the mean phenomenon.

The following example, as illustrated in the Accident Research Manual *(5)*, describes the crash characteristics at an intersection that experiences true regression to the mean effects. Consider an intersection studied over the past ten years that has annual crash frequency as shown in Figure 39. As stated in the Accident Research Manual "although the average crash frequency (over the ten year period) is 20 crashes per year, the individual crash frequency ranges between 32 and 8. It can be observed that each point that deviates from the average, and the crash frequency for the following year. In each case, the deviant points have regressed to the overall mean without any treatment being implemented" *(5)*.

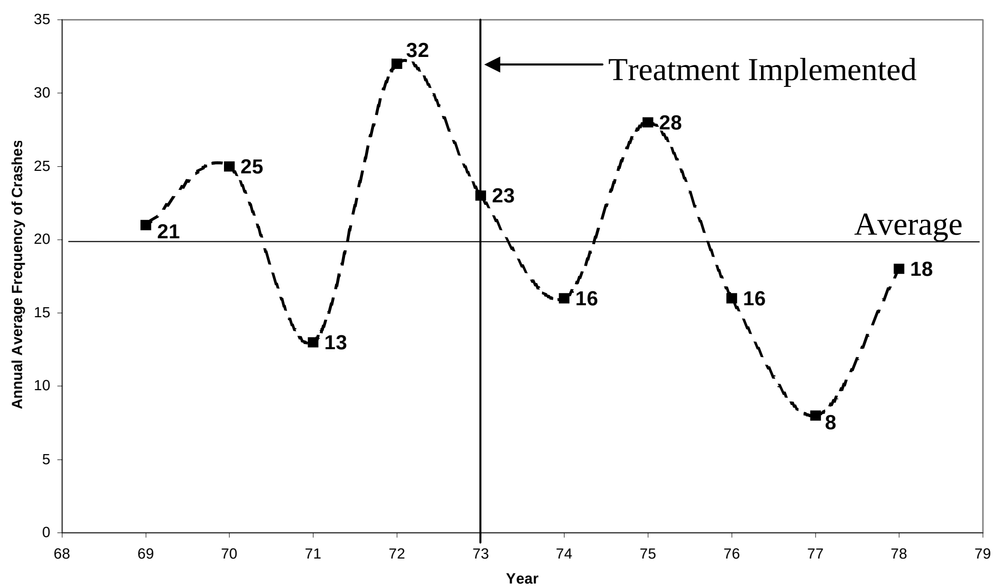


Figure 39. Trend Analysis for a Sample Intersection that Experiences Regression to the Mean [Source: Accident Research Manual, Federal Highway Administration *(5)*]

Suppose certain improvements were implemented at the intersection to reduce the crashes in 1972, the crash pattern shows a decrease in crashes in the year 1973 and 1974. Considering the crash trend over the period 1969 to 1978, it can be seen that this change in crashes is an overall effect of regression to the mean, and this reduction cannot be attributed to the improvements made at the intersection. This example in the Accident Research Manual (Figure 39, page 55) may have had other contributing factors such as, ineffective or inappropriate crash countermeasures being implemented and error in the crash database.

Results of the past effectiveness evaluations for the first three intersections in the City of Detroit have been published in the Journal of the Transportation Research Board [Transportation Research Record (TRR) No. 1734)] *(6)*. The 'before and after' evaluation study of the first three intersections in the City of Detroit, resulted in the following crash reductions *(6):*

- Seven Mile Road and John R Road Intersection
  - 44 percent reduction in total crashes
  - 73 percent reduction in injury crashes
- Seven Mile Road and Ryan Road Intersection
  - 48 percent reduction in total crashes
  - 65 percent reduction in injury crashes
- Hubbell Road and Puritan Road Intersection
  - 57 percent reduction in total crashes
  - 53 percent reduction in injury crashes

These reductions as reported in TRR 1734 were based on three years of 'before' crash data converted to an annual average and approximately two years of 'after' data, also converted to an annual average. The crash trend for these intersection does not show any underlying patterns of regression to the mean effects, but shows two completely different sets of trends in the 'before' and 'after' periods (refer to Figure 21 on page 41, Figure 23 on page 43, and Figure 25 on page 44).

It is important to note that regression to the mean effects may not necessarily occur at all high crash locations. The following example of one of the initial study intersections will be used to illustrate this point, five years of 'after' data has been accumulated at this location.

The annual trend of total and injury crashes at the intersection of Hubbell Road and Puritan Road for a eight-year period, including both the 'before' and 'after' data is shown in Figure 40. The average total crashes for the 'before' period is 35 per year, with a standard deviation of 2.0 crashes per year. The average total crashes in the 'after' period is 14.6 per year, with a standard deviation of 2.6. In the 'after' period, it is evident that the crashes have reduced due to implemented safety improvements. The yearly trend analysis as shown in Figure 40 does not exhibit any substantial regression to the mean effects from the 'before' to the 'after' period. Therefore, chances of incorrectly attributing credit to the improvements are very low.

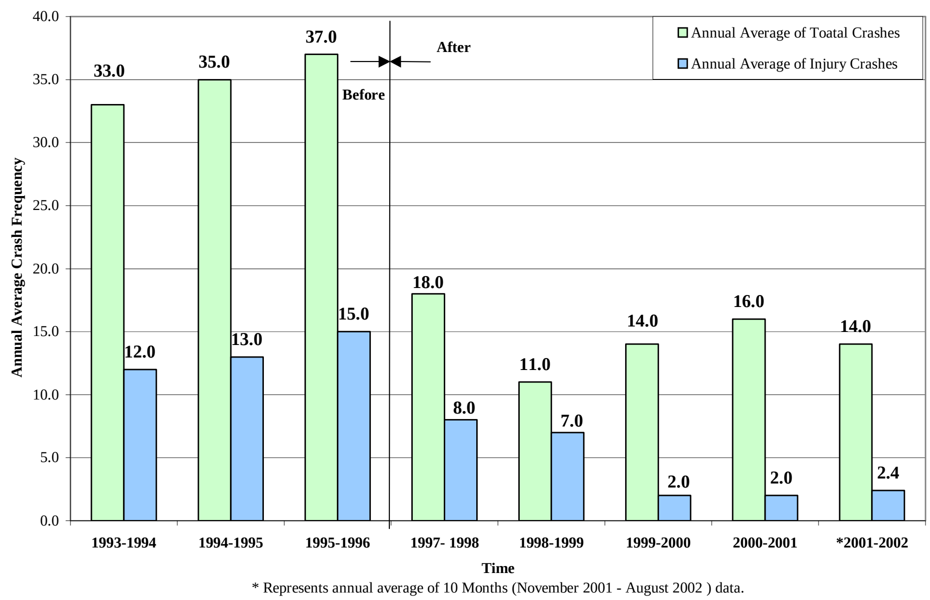


Figure 40. Trend Analysis of Total and Injury Crashes for the Hubbell Road and Puritan Road Intersection

The use of 'before and after with control' studies minimizes the effects of regression to the mean bias. "Establishment of control groups, where possible, is perhaps the best method for obtaining estimates of what the number of 'after' period accidents would have been without treatment" *(4)*. Persaud and Hauer state that when the establishment of control sites is not possible, the Empirical Bayes method may be applied *(4)*.

In this evaluation report, 'before and after' studies were performed for each intersection, each corridor and for the targeted crashes and injuries. However, additional analyses including the 'before and after with control' study, and the Empirical Bayes method for debiasing crash data was performed for a sample of improvement sites in order to demonstrate that the 'before and after' study results are valid, in comparison to the results of other methods. The 'before and after with control' study was performed for the intersections where control sites were identified. It was not possible to identify control sites for all the intersections included in this study. The Empirical Bayes method was applied to the selected high-crash intersections where regression to the mean effects are expected to occur.

The following sections present the results of the analyses performed as a part of this study.

6.2 'Before and After' (B&A) Study

The effectiveness of the improvements were statistically tested for significance based on the 'before and after' study in order to determine whether the reductions in traffic crashes occurred due to the implemented countermeasure, or due to other factors unrelated to the improvements.

Since traffic crash data is discrete and assumed to occur randomly, the Poisson test was used to test the significance of changes in the crash measures of effectiveness *(7,8)*. The six corridors and the isolated intersections were evaluated using the Poisson test. The crash measures of effectiveness used in this analysis include:

- Total crashes
- Injury crashes
- Specific crash types, mainly
    - Angle crashes
    - Left-turn head-on crashes

The results of the ‘before and after’ effectiveness evaluation using the Poisson test of significance for the statistical analysis, and annual averages of multi-year B&A crash data are summarized in Tables 1 and 2.

Table 1. Results of the ‘Before and After’ Evaluation for the Study Corridors

CORRIDOR INTERSEC-TIONS	ANNUAL AVEERAGE CRASH FREQUENCY AND PERCENT CRASH REDUCTIONS											
	ANGLE			LEFT-TURN HEAD-ON			TOTAL			INJURY		
	BEFORE	AFTER	% REDUC-TION	BEFORE	AFTER	% REDUC-TION	BEFORE	AFTER	% REDUC-TION	BEFORE	AFTER	% REDUC-TION
Woodward Avenue Corridor (33 signalized intersections)	116.0	28.1	76%*	32.5	45.5	-40%* (Increase)	**469.5**	**313.1**	**33%***	137.5	74.8	46%*
Grand River Avenue Corridor (8 signalized intersections)	19.5	22.2	-14% (Increase)	11.0	9.2	16%	**144.5**	**136.5**	**6%**	37.5	47.0	-26%* (Increase)
Wyoming Road Corridor (5 signalized intersections)	43.8	21.1	52%*	21.5	5.2	76%*	**176.2**	**103.1**	**41%***	47.7	21.1	56%*
Burton Street Corridor (8 signalized intersections)	30.0	11.3	62%*	42.5	17.8	58%*	**199.0**	**132.4**	**33%***	54.0	30.5	44%*
Division Avenue Corridor (9 signalized intersections)	35.5	21.8	39%*	45.0	18.9	58%*	**208.0**	**183.5**	**12%***	62.0	38.5	38%*
Eastern Avenue Corridor (9 signalized intersections)	41.5	11.6	72%*	24.6	11.3	54%*	**151.4**	**101.0**	**33%***	42.3	16.8	60%*

* Denotes significant reduction/increase in crashes at 95 percent Level of Confidence

Table 2. Results of the 'Before and After' Evaluation of the Isolated Intersections

ISOLATED HIGH CRASH LOCATIONS	ANNUAL AVEERAGE CRASH FREQUENCY AND PERCENT CRASH REDUCTIONS											
	ANGLE			LEFT-TURN HEAD-ON			TOTAL			INJURY		
	BEFORE	AFTER	% REDUC-TION	BEFORE	AFTER	% REDUC-TION	BEFORE	AFTER	% REDUC-TION	BEFORE	AFTER	% REDUC-TION
Seven Mile Road and John R Road	12.0	4.2	65%*	15.0	2.8	81%*	**51.7**	**25.4**	**51%***	16.7	6.0	64%*
Seven Mile Road and Ryan Road	18.3	3.8	79%*	20.0	2.6	87%*	**68.0**	**31.4**	**54%***	18.7	5.3	72%*
Hubbell Road and Puritan Road	20.3	3.1	85%*	4.0	1.0	75%**	**35.0**	**14.7**	**58%***	13.3	4.3	68%*
Schoolcraft Road and Evergreen Road	5.3	1.8	66%*	7.3	5.0	32%	**37.9**	**25.0**	**34%***	14.7	8.8	40%*
Leonard Street and College Avenue	4.0	1.3	68%**	7.5	1.3	83%*	**25.0**	**7.8**	**69%***	5.5	2.8	49%
Harper Avenue and Cadieux Avenue	2.0	0.9	55%**	1.0	0.0	100%**	**35.0**	**25.8**	**26%**	5.0	3.7	26%
Harper Avenue and Dickerson Road	8.0	3.7	54%*	7.0	8.3	-19% (In-crease)	**34.0**	**30.5**	**10%**	10.0	7.4	26%
Cadieux Avenue and I-94 Service Drives	11.0	1.8	84%*	0.0	0.0	0%**	**28.0**	**15.7**	**44%***	6.0	5.5	8%
Dexter Road and Davison Avenue	4.0	3.0	25%**	6.0	6.0	0%	**40.0**	**45.0**	**-12% (In-crease)**	11.0	13.5	-23% (In-crease)
McNichols Road and Schaefer Highway	2.0	2.0	0%**	8.0	2.0	75%*	**40.0**	**40.0**	**0%**	14.0	8.0	43%*
Schaefer Highway and Seven Mile Road	6.0	0.0	100%*	3.0	1.5	50%**	**37.5**	**18.0**	**52%***	10.5	4.5	57%*

* Denotes significant reduction/increase in crashes at 95 percent Level of Confidence

** Denotes too low of a frequency of 'before' crash data

The results of this analysis indicated that the countermeasures installed were effective in reducing the targeted crash types. The following are the countermeasures, in general that were aimed at mitigating angle and injury crashes:

- Installation of all-red intervals with lengths calculated as per the ITE guidelines *(2)*.
- Relocation of the signal heads to improve visibility.
- Realignment of signal heads over travel lanes to improve visibility.
- Replacement of 8-inch signal lenses to 12-inch lenses.
- Installation of back plates on the traffic signal (Burton Street corridor, Grand Rapids).

The countermeasures aimed at mitigating left-turn head-on and injury crashes are as follows:

- Installation of secondary post mounted left-turn signals
- Installation of exclusive left-turn lanes and permissive/protected phases

It should be noted that evaluations were not performed for the isolated intersections of Linwood Avenue and Davison Avenue in City of Detroit, and Michigan Street and Ottawa Avenue in the City of Grand Rapids.

The crash patterns at the intersection of Linwood Avenue and Davison Avenue were observed to have changed during the ‘after’ period. This could be attributed to the two new major commercial developments at this location. A large grocery store and a fast food restaurant at the corner of the intersection have been built during the ‘after’ improvement period, and were not considered when developing the safety treatments. Thus, the land use characteristics and traffic patterns have dramatically changed near the intersection, which generate significant in and out traffic movements at the driveway locations in close proximity to the intersection, that did not previously exist. Additionally, as a result of changes in the maintenance responsibility from the City of Detroit to Wayne County, the safety treatment of all-red intervals in the signal timing plans were eliminated. An evaluation should be performed at a location when the only changes made at the location are those of the implementation of the safety countermeasures. Therefore, performing an evaluation at this location will not result in a true evaluation of the implemented countermeasures.

At the Michigan Street and Ottawa Avenue intersection, the critical safety improvements that were recommended at this intersection were not installed. Thus, in reality the crash experience is not expected to change. Therefore, it was not included in the evaluation study.

6.3 Analysis of the Effect of the Implemented Treatments

An analysis was performed to verify if the implemented safety treatments were not only effective at a corridor level, but also consistently effective at the individual test sites along the corridor.

When performing statistical analyses, traffic crash data for individual intersections with similar installed countermeasures are typically combined in order to improve the reliability of the results. The crash frequencies at individual intersections alone can sometimes be too low to draw any meaningful conclusions. Thus, when performing statistical analyses for groups of intersections combined, care must be taken to account for the following *(9)*:

- Crash data for the 'before' and 'after' periods for the test sites are compared with that of a large control area for the same time periods to determine an accurate estimate of the effectiveness of specific countermeasures.
- The effect of safety treatments is the same at all the sites.
- The variability in the effect of the safety treatment(s) from location to location.

The methodology and statistical tests as presented by Tanner *(9)* were applied to the study corridors in the cities of Detroit and Grand Rapids. This methodology is based on a binomial distribution which considers the 'before' and 'after' crash frequencies, as well as a factor to represent the crash experience for a large control area.

The parameter 'k' is also introduced in this methodology, which is a measure of the apparent effect of the change at a site. "It is the ratio of accidents after to the number that would have been expected if the change had no effect" *(9)*. Please note that 'κ' is the true value of 'k', that is, the value that 'k' would take if the number of crashes in the 'before' and 'after' periods took their expected values.

As a part of this analysis, the ratio of 'after' crashes to 'before' crashes for large control areas were calculated, referred to as 'C' values. As stated in Tanner's paper, the large control area "may be the whole of the police district in which the site lies" *(9).*

Thus, in this analysis the City of Detroit was used as the control area for the Woodward Avenue, Grand River Avenue and Wyoming Road corridors, and the City of Grand Rapids was used as the control area for the Burton Street, Division Avenue and Eastern Avenue corridors. The resulting value of 'C' for Detroit is 0.96, which indicates that there was an annual average of four percent decrease in crashes in the 'after' period, as compared to the 'before' period. For the City of Grand Rapids, the value of 'C' was calculated to be 1.16, which implies that the general crash trend has increased by 16 percent during the 'after' period.

The value of 'k' was estimated using the following equation:

$$\sum_{i=1}^{N} n_i / (1 + kC_i) = \sum b_i$$

Where,

- N = Number of sites from which data are to be combined
- n_i = $a_i + b_i$
- b_i = Number of traffic crashes in the 'before' period at site i (i = 1,2,……,N)
- a_i = Number of traffic crashes in the 'after' period at site i (i = 1,2,……,N)
- C_i = Ratio of traffic crashes 'after' to 'before' in the control area
- k_i = $a_i/(b_iC_i)$. This measures the apparent effect of the change at site i. It is the ratio of traffic crashes 'after' to the number that would have been expected if the change had no effect.

The following are the resulting values of k for each of the study corridors:

- Woodward Avenue Corridor: k = 0.695
- Grand River Avenue Corridor: k = 0.99
- Wyoming Road Corridor: k = 0.61
- Division Avenue Corridor: k = 0.76
- Burton Street Corridor: k = 0.57
- Eastern Avenue Corridor: k = 0.57

The Chi-Square test (χ^2) was performed to determine if there are differences in the treatment effects among the test intersections and corridors. Specifically, this test was performed to determine if there were significant differences between the average 'k' value calculated for the corridor, and the 'k_i' values resulting from the individual intersections within the corridors.

The equation used to calculate the Chi-Square value is as follows:

$$\chi^2 = \left[\frac{b_i^2 C_i}{(a_i + b_i)} \times \frac{(K - k_i)^2}{K} \right]$$

The results of the significance tests are summarized in Table 3.

Table 3. Results of Significance Test to Determine Differences Between the Average Effect of the Countermeasures (k) and Their Effect at Individual Locations (k_i)

CORRIDOR	NUMBER OF SIGNALIZED INTERSECTIONS (N)	AVERAGE 'k' VALUE	χ^2 CALCULATED	χ^2 CRITICAL AT N-1 DEGREES OF FREEDOM AND $\alpha = 0.05$	SIGNIFICANT DIFFERENCE AT 95% LEVEL OF CONFIDENCE?
Woodward Avenue Corridor	33	0.695	35.56	46.18	NO
Grand River Avenue Corridor	8	0.99	4.77	14.07	NO
Wyoming Road Corridor	5	0.61	6.86	9.49	NO
Division Avenue Corridor	9	0.76	6.66	15.51	NO
Burton Street Corridor	8	0.57	1.68	14.07	NO
Eastern Avenue Corridor	9	0.57	11.23	15.51	NO

The result of these tests <u>not</u> being significant is desirable, since it implies that the effect of the countermeasures were consistent from location to location. Thus, the effects of the safety treatments are essentially the same at the individual intersection locations and corridors.

A t–test was then performed to determine the statistical significance of the effectiveness of the implemented safety treatments in general. The t-test (one-tailed) was used to determine if the effectiveness of the implemented treatments are statistically significant. The t-statistic was calculated using the following equation *(9)*.

$t = \ln(k) / SE \ln(k)$

Where: Standard Error (SE) $\ln(k) = \sqrt{\text{Var} \ln(k)}$, and

$$\text{Var} \ln (k) = \frac{(1+\phi)\left(1 + \frac{2}{\Sigma n_i}\right)}{\Sigma \frac{\kappa C_i n_i}{(1 + \kappa C_i)^2}}$$, and

$$\phi = \left(\frac{\chi^2}{N - 1} - 1 \right) \frac{N \Sigma n_i^2}{(\Sigma n_i)^2}$$

It is important to note that the equation for Var ln (k) can be simplified as follows:

- Omit the term $1 + \phi$ when there is no evidence that κ_i varies from site to site.
  - Since the k_i values at the individual intersections of the corridors studied were not significantly different than the average k values, no evidence was found that k_i varies from site to site. Thus this simplification may be used.
- Omit the term $1 + (2/\Sigma n_i)$, if Σn_i is reasonably large, say greater than 40.
  - The Σn_i values (sum of before and after crash frequencies) exceeded 200 for all the corridors, thus this simplification may be used.
- Replace the denominator, $\Sigma \frac{kC_i n_i}{(1 + \kappa C_i)^2}$, by $\frac{1}{4}\Sigma n_i$, if most of the values of κC_i are in the range of ½ to 2.
  - Since the values of κC_i ranged from 0.58 to 0.95 for the intersections and corridors, this simplification can also be used.

Thus, the equation for Var ln(k) can be simplified to:

$$\text{Var} \ln (k) = \frac{1}{\frac{1}{4}\Sigma n_i}$$

The details and results of the statistical t-test are summarized in Table 4.

Table 4. Statistical Testing (t-test) of the Significance of the Effect of the Implemented Countermeasures

CORRIDOR	k	LN(k)	VAR LN(k)	SE LN(k)	t-CALCULATED	t-CRITICAL AT N-1 DEGREES OF FREEDOM	SIGNIFICANT DIFFERENCE
Woodward Avenue Corridor (33 Intersections)	0.695	-0.36	0.00511	0.0715	-5.09	1.69	Yes at 95% Level of Confidence (LOC)
Grand River Avenue Corridor (8 Intersections)	0.99	-0.01	0.01423	0.1193	-0.08	1.90	No
Wyoming Road Corridor (5 Intersections)	0.61	-0.49	0.01433	0.1197	-4.13	2.13	Yes at 95% LOC
Division Avenue Corridor (9 Intersections)	0.76	-0.27	0.01021	0.1011	-2.72	1.86	Yes at 95% LOC
Burton Street Corridor (8 Intersections)	0.57	-0.56	0.01207	0.1099	-5.12	1.90	Yes at 95% LOC
Eastern Avenue Corridor (9 Intersections)	0.57	-0.56	0.01936	0.1391	-4.04	1.86	Yes At 95% LOC

The results of this comprehensive analysis indicated that the implemented safety treatments were not only effective at a corridor level, but also consistently effective at all the individual test sites at all the corridors, except for the Grand River Avenue corridor. Therefore, the countermeasures, which include installing larger signal heads, all-red intervals, black plates, and others on the whole tend to significantly reduce crash frequencies when properly installed.

6.4 Additional Statistical Analyses

Additional analyses were performed for a sample of selected test sites in the cities of Detroit and Grand Rapids where traffic volume data for the ‘before’ and ‘after’ periods were available. These additional studies included the following:

- B&A studies based on crash frequencies and rates, which were adjusted for volume changes in the ‘before’ and ‘after’ periods.
- B&A with control studies based on crash frequencies and rates, which were adjusted for volume changes in the ‘before’ and ‘after’ periods.

Eight Selected Test Sites in the Cities of Detroit and Grand Rapids:

Four of the selected intersections are located along the study corridors and four are isolated intersections in Detroit and Grand Rapids. The following are the selected test sites in which additional analyses were performed:

1. Leonard Street and College Avenue intersection
2. Burton Street and Kalamazoo Avenue intersection
3. Burton Street and Breton Street intersection
4. Eastern Avenue and Franklin Avenue intersection
5. Seven Mile Road and Ryan Road intersection
6. Hubbell Road and Puritan Road intersection
7. Wyoming Road and Lyndon Road intersection
8. Schaefer Highway and Seven Mile Road intersection

These eight sites were selected because they had total crash reductions greater than 35 percent, for total, injury, and the targeted crash types, based on the ‘before and after’ studies, and had annual average total crash frequencies of greater than 20 crashes per year in the ‘before’ period. These intersections were considered candidate locations where regression to the mean effects may be observed.

The evaluations performed at these locations will compare the results of ‘before and after’ study with the results of the ‘before and after with control’ study. The ‘before and after with control’ study is considered to be one of the most effective studies in highway safety evaluation.

In addition to the Poisson test of significance, two other statistical tests, the Chi-Square test and Paired t-test were also used to determine the statistical significance of the change in traffic crashes due to the implementation of the safety treatments at the test intersections.

6.4.1 *Chi-Square Test of Significance*

The Chi-Square (χ^2) test was used to determine if the observed frequencies of crashes at these locations are truly independent of the expected crash frequencies without treatment. The null hypothesis assumed is: *there is no significant difference between the observed frequencies and the expected frequencies*, and is rejected when the $\chi^2_{\text{calculated}}$ is greater than the χ^2_{critical} at α = 0.05 (95 percent level of confidence). The Chi-Square test can be used to test both discrete data (crash frequency) and continuous data (crash rates). The calculated Chi-Square value can be determined using the following equation *(5)*:

$$\chi^2_{\text{calculated}} = \sum_{j=1}^{k} \left[(N_{Aj} - \hat{N}_{Aj})^2 / \hat{N}_{Aj} \right]$$

Where,

$$\hat{N}_{Aj} = \frac{t_{Aj}}{2} \left[\frac{N_{Bj}}{t_{Bj}} + \frac{N_{Aj}}{t_{Aj}} \right]$$

t_{Aj} = length of the j-th time period for the after (A) sample; likewise for t_{Bj}

N_{Aj} = number of accidents in the j-th time period for the after (A) sample; Likewise for N_{Bj}

k = number of locations

6.4.2 *Paired t-Test*

The Paired t-test was used to test if the means of the expected crash rate without treatment are statistically different from the means of the observed 'after' crash rate at the selected locations. The null hypothesis assumed is *there is no significant difference between the observed mean crash rates and the expected mean crash rate*, and is rejected if the $t_{calculated}$ value is greater than the $t_{critical}$ value at an $\alpha = 0.05$ (95 percent level of confidence). The Paired t-test can be used to test only continuous data. Thus, only crash rates were considered in this analysis. The t-statistic can be calculated according to the following equation *(4)*:

$$t_{calculated} = \frac{\overline{x}_B - \overline{x}_A}{s_D / \sqrt{N}}$$

Where,

$\overline{x}_B$ = Before sample mean

$\overline{x}_A$ = After sample mean

$$s_D^2 = s_B^2 + s_A^2 - 2\left(\frac{1}{N-1} \sum_{i=1}^{N} (x_{Bi} - \overline{x}_B)(x_{Ai} - \overline{x}_A)\right)$$

N = Number of locations

6.5 'Before and After' Study at the Selected Test Sites

Traffic crash frequencies and rates were determined for the eight selected test sites in the cities of Detroit and Grand Rapids. Three statistical tests were then used to determine the effectiveness of the percent reductions based on the 'before and after' study.

The results of the tests, as well as the data, are shown in Table 5 for the Poisson test for crash frequencies, Table 6 for the Chi-Square test for crash frequencies, and Table 7 for the Paired t-test for crash rates.

Poisson Test of Significance for Crash Frequency (B&A Study)

Table 5. Results of the Poisson Test of Significance for Crash Frequency Based on the 'Before and After' Study for the Eight Selected Test Intersections

LOCATION	TEST INTERSECTIONS	PERCENT CRASH REDUCTIONS			
		Angle	**Left-Turn Head-On**	**Total**	**Injury**
DETROIT	Seven Mile Road and Ryan Road	79%*	87%*	54%*	72%*
	Hubbell Road and Puritan Road	85%*	75%**	58%*	68%*
	Wyoming Road and Lyndon Road	84%*	50%	63%*	16%
	Schaefer Highway and Seven Mile Road	100%*	50%**	52%*	57%*
GRAND RAPIDS	Leonard Street and College Avenue	68%**	83%*	69%*	49%
	Burton Street and Kalamazoo Avenue	79%*	65%*	45%*	57%*
	Burton Street and Breton Avenue	20%**	79%*	42%*	40%
	Eastern Avenue and Franklin Street	83%**	72%*	24%	49%
All Sites Combined		**82%***	**75%***	**51%***	**55%***

* Denotes significant reduction in crashes at 95% Level of Confidence

** Denotes too low of a frequency of before crash data

The results of the Poisson test of significance for 'before' and 'after' crash frequencies at the eight test intersections indicate that the total crashes were significantly reduced by a range of 24 to 69 percent, on a location basis, and by 51 percent for the study intersections combined, based on the B&A study.

Chi-Square Test for Crash Frequencies (B&A Study)

Table 6. Data Used in the Chi-Square Test Based on the 'Before and After' Study for the Eight Selected Test Intersections

LOCATION	TEST INTERSECTIONS	BEFORE PERIOD CRASH FREQUENCY N_B FOR (TIME PERIOD IN YEARS)	AFTER PERIOD CRASH FREQUENCY N_A FOR (TIME PERIOD IN YEARS)
DETROIT	Seven Mile Road and Ryan Road	204 (3)	165 (5.25)
	Hubbell Road and Puritan Road	105 (3)	71 (4.83)
	Wyoming Road and Lyndon Road	41 (0.75)	15 (0.75)
	Schaefer Highway and Seven Mile Road	25 (0.67)	12 (0.67)
GRAND RAPIDS	Leonard Street and College Avenue	50 (2)	31 (3.92)
	Burton Street and Kalamazoo Avenue	72 (2)	48 (2.42)
	Burton Street and Breton Avenue	114 (2)	80 (2.42)
	Eastern Avenue and Franklin Street	52 (2)	33 (1.67)

$\chi^2_{calculated} = 95.40$; $\chi^2_{critical} = 14.07$ at $\alpha = 0.05$ (95 percent level of confidence) and 7 degrees of freedom

Since $\chi^2_{calculated}$ is greater than $\chi^2_{critical}$, there is a significant difference between the 'before' crash frequency and 'after' crash frequency at the eight study intersections based on Chi-Square Test.

Paired t-Test for Crash Rates (B&A Study)

In order to perform the Paired t-test, the total crash rates for 'before' and 'after' periods were calculated as shown in Table 7. Instead of assuming that the 'before' crash rates were equal to the expected 'after' crash rates without treatment, adjustments for volume changes were made to eliminate potential errors due to changes in traffic volumes.

Table 7. Crash Rates Used in the Paired t-Test Calculations for the 'Before and After' Study for the Eight Selected Test Intersections

LOCATION	TEST INTERSECTIONS	EXPECTED CRASH RATE* WITHOUT TREATMENTS ADJUSTED TO THE AFTER VOLUME	AFTER CRASH RATE*
DETROIT	Seven Mile Road and Ryan Road	6.59	3.05
	Hubbell Road and Puritan Road	4.31	1.81
	Wyoming Road and Lyndon Road	4.16	1.52
	Schaefer Highway and Seven Mile Road	2.50	1.20
GRAND RAPIDS	Leonard Street and College Avenue	1.74	0.54
	Burton Street and Kalamazoo Avenue	2.70	1.49
	Burton Street and Breton Avenue	2.41	1.40
	Eastern Avenue and Franklin Street	2.65	2.02

* Crashes per million entering vehicles

Mean of expected crash rate without treatment = 3.38 crashes/ million entering vehicles

Mean of 'after' crash rate = 1.63 crashes/ million entering vehicles

Variance of the expected crash rate without treatment = 2.46

Variance of the 'after' crash rate = 0.52

$t_{calculated} = 4.90$

$t_{critical}$ (one-tail test) = 1.895 at $\alpha = 0.05$

Since $t_{calculated}$ is greater that $t_{critical}$ at 95 percent level of confidence, a **significant difference** in the 'before' crash rate and 'after' crash rate is found.

Therefore, based on all three statistical tests using the B&A study at the eight sample intersections in Detroit and Grand Rapids, <u>significant reductions in the traffic crashes were observed during the 'after' period and thus, can be attributed to the safety treatments implemented as a part of the RIDP.</u>

6.6 'Before and After With Control' Studies

Control Site Selection

The use of control sites helps to observe the probable changes in crash patterns of the test site, if the countermeasures had not been implemented. The control sites were selected based on their intersection geometry and traffic volume similarity to the 'before' condition of the test sites, and most importantly, proximity to the test sites. The pairs of test and control intersections in Detroit and Grand Rapids are shown in Table 8.

Table 8. Selected Test and Control Sites

LOCATION	NUMBER	TEST SITE	CONTROL SITE
Detroit	1	Seven Mile Road and Ryan Road	Seven Mile Road and Dequindre Road
	2	Hubbell Road and Puritan Road	Meyers Road and Puritan Road
	3	Wyoming Road and Lyndon Road	Hubbell Road and Joy Road
	4	Schaefer Highway and Seven Mile Road	Evergreen Road and Seven Mile Road
Grand Rapids	1	Leonard Street and College Avenue	Leonard Street and Lafayette Avenue
	2	Burton Street and Kalamazoo Avenue	Michigan Street and College Avenue
	3	Burton Street and Breton Avenue	Michigan Street and Fuller Avenue
	4	Eastern Avenue and Franklin Street	Fulton Street and Lafayette Avenue

Since adjustments for changes in the traffic volumes for both the 'before' and 'after' periods were considered, traffic volume data for the test and control intersections were obtained. The intersection approach volume data for the test sites for the 'before' period was obtained from the pre-implementation study reports. In addition, midblock average daily traffic (ADT) volumes were available from the Grand Valley Metro Traffic Count report for the test and control intersections in Grand Rapids, as well as from the City of Detroit. Where approach counts for the control sites were not readily available, proportions of the intersection approach volume to the midblock counts were determined at the test site, and were used to estimate the approach volumes at the control sites for the 'before' period.

Midblock traffic volumes for the 'after' period were collected by the City of Grand Rapids and the City of Detroit for the test and control sites. These were used to determine the 'after' period intersection approach volumes. For the roadways in Grand Rapids and Detroit in which 'after' traffic volumes were not available, an average traffic growth factor was calculated and applied to the test and control intersections.

The traffic volumes for the 'before' and 'after' periods for the test and control sites are included in Appendix IX.

In order to perform the 'before and after with control' study, the expected crash frequency of the test site, if no improvements were made, was calculated. The expected frequencies of crashes without treatment is calculated in proportion to the change in crashes to the control site during the 'before' and 'after' periods. The tests are performed using these adjusted expected frequencies.

The expected crash rate at the test site without treatment, with respect to the control site is given by *(7):*

$$E_R = B_{PR} (A_{CR}/B_{CR})$$

Where,

B_{PR} = 'Before' crash rate at the project (test) site per million entering vehicles

A_{CR} = 'After' crash rate at the control site per million entering vehicles

B_{CR} = 'Before' crash rate at the control site per million entering vehicles

E_R = Expected crash rate at the test site without treatment per million entering Vehicles

The expected crash frequency at the test site without treatment is given by:

$$E_F = E_R (ADT_A)(365)/10^6$$

Where,

ADT_A = Average Daily Traffic at the test site for the 'after' period, vehicles per day (vpd)

‘Before and after with control’ analysis using crash rates adjusted for volume changes during the ‘before’ and ‘after’ periods were performed for the selected pairs of test and control sites. Table 9 shows details of the ‘before’ and ‘after’ crash frequencies and rates, as well as the percent reduction, based on this analysis.

Table 9. Traffic Crash Data Used in the ‘Before and After with Control’ Study for the Eight Selected Sites

SITE	INTERSECTION	‘BEFORE’ PERIOD		OBSERVED ‘AFTER’ PERIOD		EXPECTED AFTER WITHOUT TREATMENT		PERCENT REDUCTION**
		Frequency (crashes/year)	Rate*	Frequency (crashes/year)	Rate*	Frequency (crashes/year)	Rate*	
Test	Leonard Street and College Avenue	25.0	2.25	7.8	0.54	40.4	2.82	81%
Control	Leonard Street and Lafayette Avenue	15.0	1.81	23.2	2.27	-	-	
Test	Burton Street and Kalamazoo Avenue	36.0	2.67	19.9	1.49	37.5	2.82	47%
Control	Michigan Street and College Avenue	31.0	2.23	30.9	2.35	-	-	
Test	Burton Street and Breton Avenue	57.0	2.57	33.1	1.40	45.0	1.90	27%
Control	Michigan Street and Fuller Avenue	50.0	2.83	39.5	2.10	-	-	
Test	Eastern Avenue and Franklin Street	26.0	2.58	19.8	2.02	33.0	3.38	40%
Control	Fulton Street and Lafayette Avenue	22.0	1.66	27.2	2.17	-	-	
Test	Seven Mile Road and Ryan Road	68.0	7.30	31.4	3.05	51.0	4.95	38%
Control	Seven Mile Road and Dequindre Road	42.0	5.22	32.0	3.54	-	-	
Test	Hubbell Road and Puritan Road	35.0	4.14	14.7	1.81	19.6	2.41	25%
Control	Meyers Road and Puritan Road	37.0	3.37	22.0	1.96	-	-	
Test	Wyoming Road and Lyndon Road	54.7	4.24	20.0	1.52	40.5	3.09	51%
Control	Hubbell Road and Joy Road	27.0	2.67	20.0	1.95	-	-	
Test	Schaefer Highway and Seven Mile Road	37.5	2.12	18.0	1.20	33.4	2.22	46%
Control	Evergreen Road and Seven Mile Road	55.0	3.14	59.0	3.29	-	-	

*Crashes per million entering vehicles

**Percent reduction = (Expected After Without Treatment$_{\text{Test Site}}$ – Observed After$_{\text{Test Site}}$)/Expected After Without Treatment$_{\text{Test Site}}$

The crash frequencies for the test and control sites based on volume adjustments for the ‘before’ and ‘after’ periods are presented graphically in order to show the percent reduction based on the ‘before and after with control’ study, as well as how these results compare with the ‘before and after’ results at the test sites. The graphs are presented in Figures 41 through 48.

For the intersection of Leonard Street and College Avenue, the results of the analysis based on the traffic crash and volume characteristics at the control site indicate that 81 percent of the reduction in crashes is attributable to the safety treatments. Please note that the reduction based on the ‘before and after’ study is much less, 69 percent. Considering only the total crash frequency at the test site, the crashes reduced from an annual average of 25 crashes per year to 7.8 per year, as shown in Figure 41.

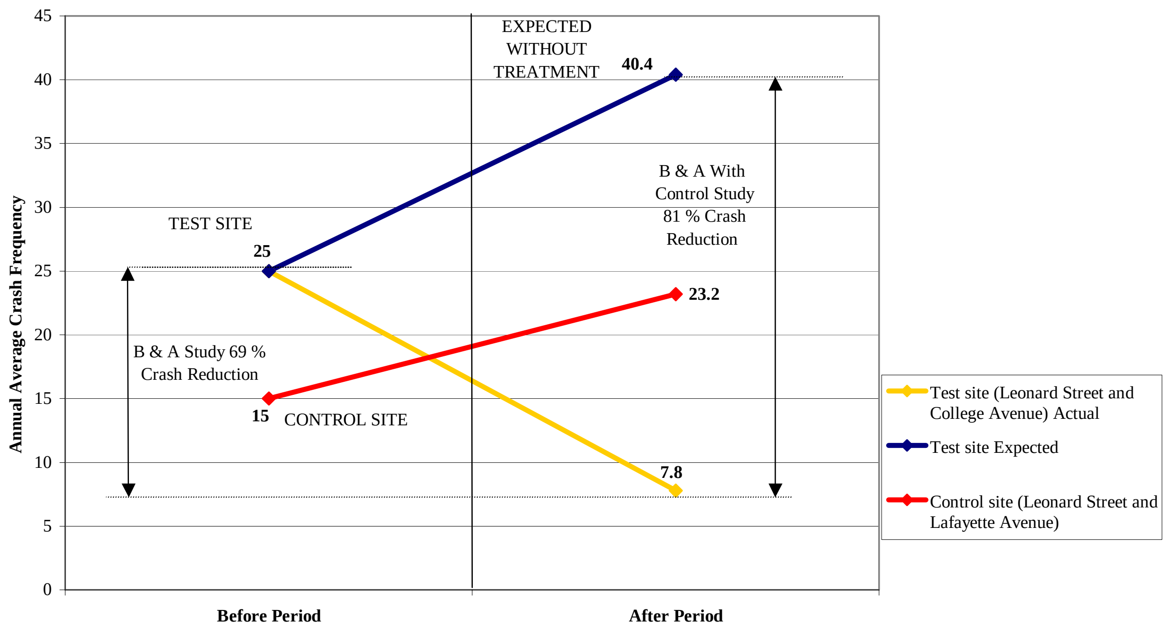


Figure 41. ‘Before and After with Control’ Study for the Leonard Street and College Avenue Test Intersection

For the intersection of Burton Street and Kalamazoo Avenue, the results of the analysis based on the traffic crash and volume characteristics at the control site indicated that 47 percent of the reduction in crashes is attributable to the safety treatments. Please note that the reduction based on the ‘before and after’ study is similar to this analysis (45 percent). Considering only the total crash frequency at the test site, the crashes reduced from an annual average of 36 crashes per year to 19.9 per year, as shown in Figure 42.

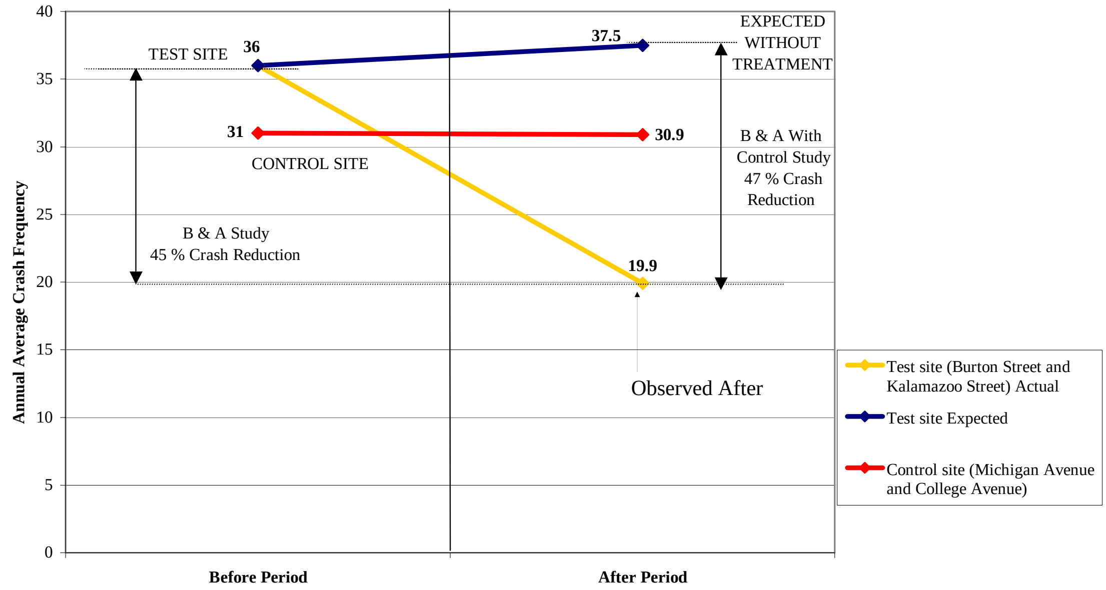


Figure 42. 'Before and After with Control' Study for the Burton Street and Kalamazoo Avenue Test Intersection

For the intersection of Burton Street and Breton Avenue, the results of the analysis based on the traffic crash and volume characteristics at the control site indicated that 27 percent of the reduction in crashes is attributable to the safety treatments. Please note that the reduction based on the 'before and after' study is higher (42 percent). Considering only the total crash frequency at the test site, the crashes reduced from an annual average of 57 crashes per year to 33.1 per year, as shown in Figure 43.

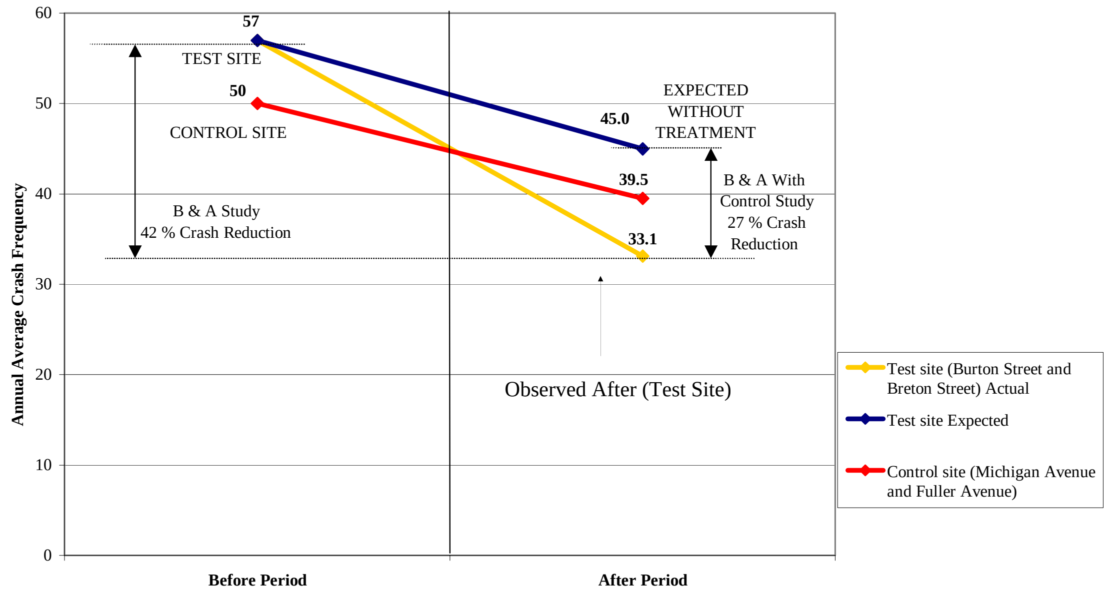


Figure 43. 'Before and After with Control' Study for the Burton Street and Breton Avenue Test Intersection

For the intersection of Eastern Avenue and Franklin Street, the results of the analysis based on the characteristics at the control site indicated that 40 percent of the reduction in crashes is attributable to the safety treatments. Please note that the reduction based on the 'before and after' study is much less (24 percent). The traffic crashes at the test site reduced from an annual average of 26 crashes per year to 19.8 per year, as shown in Figure 44.

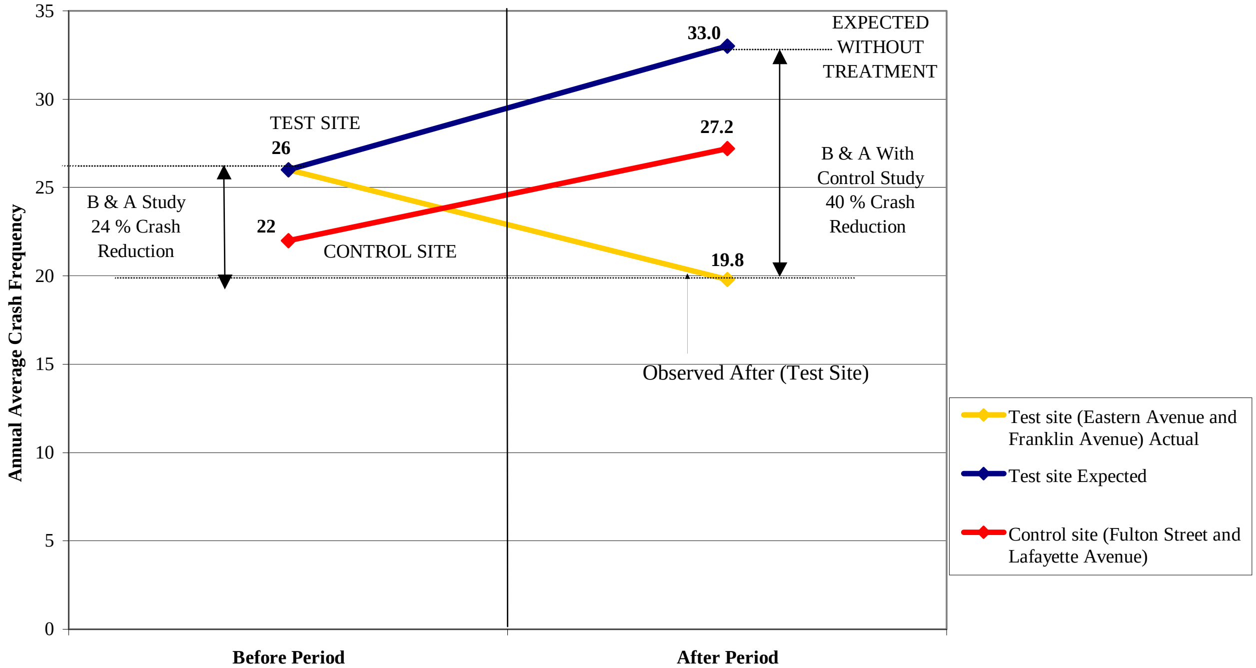


Figure 44. 'Before and After with Control' Study for the Eastern Avenue and Franklin Street Test Intersection

For the intersection of Seven Mile Road and Ryan Road, the results of the analysis based on the traffic crash and volume characteristics at the control site indicate that 38 percent of the reduction in crashes is attributable to the safety treatments. Please note that the reduction based on the 'before and after' study is higher, 54 percent. Considering only the total crash frequency at the test site, the crashes reduced from an annual average of 68 crashes per year to 31.4 per year, as shown in Figure 45.

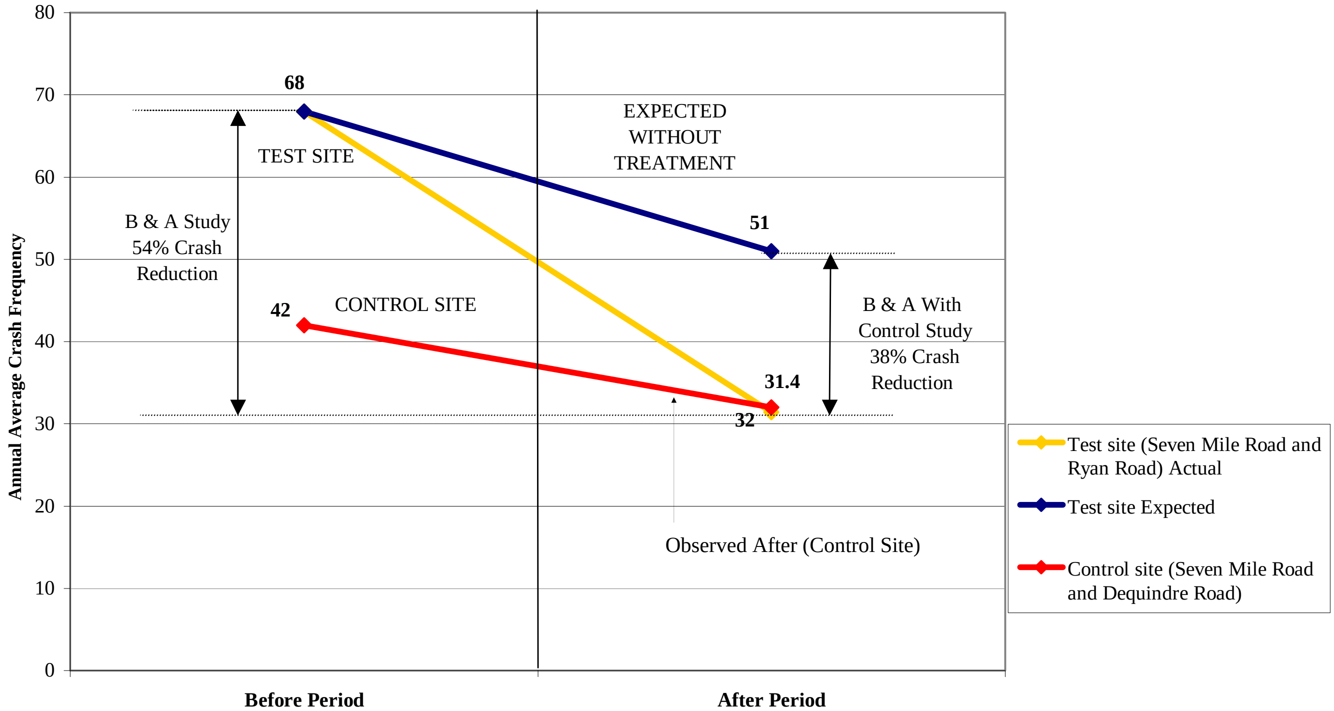


Figure 45. 'Before and After with Control' Study for the Seven Mile Road and Ryan Road Test Intersection

For the intersection of Hubbell Road and Puritan Road, the results of the analysis based on the traffic crash and volume characteristics at the control site indicate that 25 percent of the reduction in crashes is attributable to the safety treatments. Please note that the reduction based on the 'before and after' study is much higher, 58 percent. Considering only the total crash frequency at the test site, the crashes reduced from an annual average of 35 crashes per year to 14.7 per year, as shown in Figure 46.

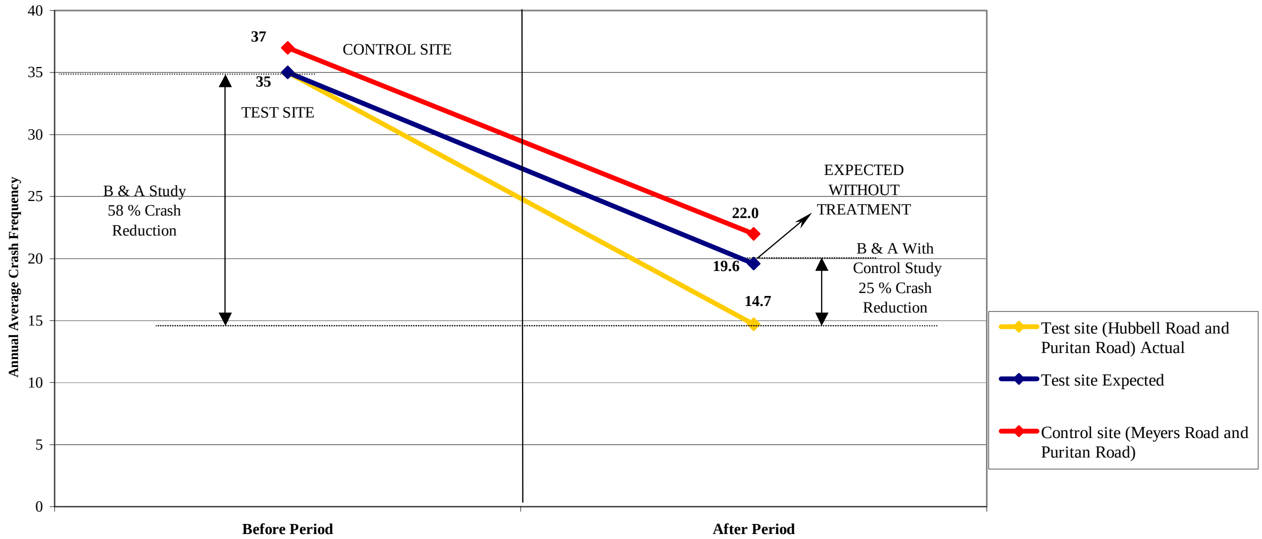


Figure 46. 'Before and After with Control' Study for the Hubbell Road and Puritan Road Test Intersection

For the intersection of Wyoming Road and Lyndon Road, the results of the analysis based on the traffic crash and volume characteristics at the control site indicate that 51 percent of the reduction in crashes is attributable to the safety treatments. Please note that the reduction based on the 'before and after' study is higher, 63 percent. Considering only the total crash frequency at the test site, the crashes reduced from an annual average of 54.7 crashes per year to 20 per year, as shown in Figure 47.

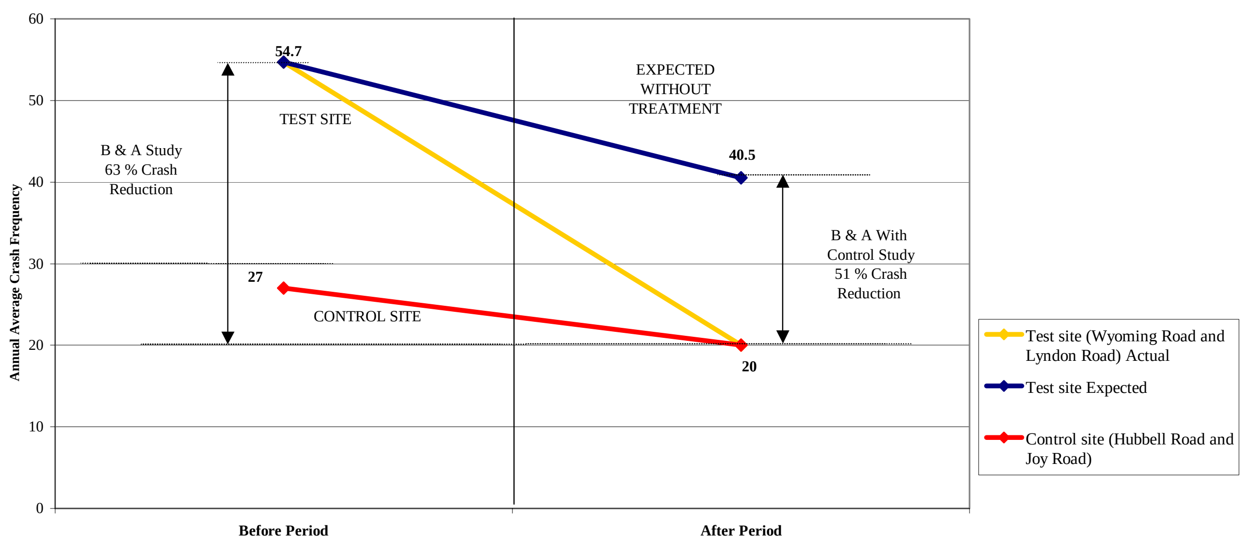


Figure 47. 'Before and After with Control' Study for the Wyoming Road and Lyndon Road Test Intersection

For the intersection of Schaefer Highway and Seven Mile Road, the results of the analysis based on the traffic crash and volume characteristics at the control site indicate that 37 percent of the reduction in crashes is attributable to the safety treatments. Please note that the reduction based on the 'before and after' study is much higher, 52 percent. Considering only the total crash frequency at the test site, the crashes reduced from an annual average of 37.5 crashes per year to 18.0 per year, as shown in Figure 48.

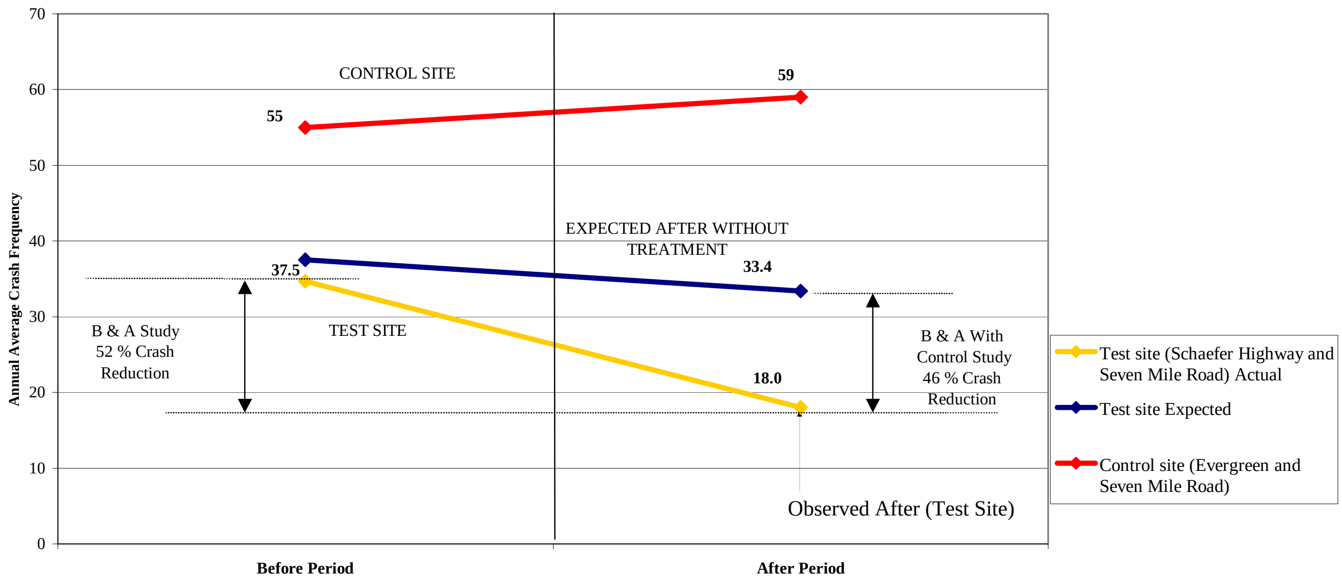


Figure 48. 'Before and After with Control' Study for the Schaefer Highway and Seven Mile Road Test Intersection

A set of statistical analyses were performed in order to determine if the total crash reductions based on the 'before and after with control' studies were significant. The statistical tests performed included the Poisson Test, the Chi-Square test and the Paired t-test. The results of the tests as well as the data used in the calculations are shown in Tables 10 for the Poisson Test, Table 11 for the Chi-Square test, and Table 12 for the Paired t-test.

Poisson Test of Significance for Crash Frequency (B&A with Control Study)

Table 10. Results of the Poisson Test of Significance Based on the 'Before and After with Control' Study for the Eight Selected Sites

SELECTED INTERSECTIONS	PERCENT REDUCTION IN TOTAL CRASHES
Leonard and College	81%*
Burton and Kalamazoo	47%*
Burton and Breton	27%*
Eastern and Franklin	40%*
Seven Mile Road and Ryan Road	38%*
Hubbell Road and Puritan Road	25%
Wyoming Road and Lyndon Road	51%*
Schaefer Highway and Seven Mile Road	46%*
Percent reduction at all the test locations combined	**45%***

* Denotes a significant reduction in crashes at 95 percent level of confidence

The results of the Poisson test indicated that the percent reductions for the combined sample test sites in the cities of Detroit and Grand Rapids based on the 'before and after with control' study are significant at 95 percent level of confidence.

Chi-Square Test for Crash Frequencies (B&A with Control Study)

Table 11. Data Used in the Chi-Square Test Based on the 'Before and After with Control' Study for the Eight Selected Sites

INTERSECTIONS	CALCULATED EXPECTED CRASH FREQUENCY WITHOUT TREATMENT N_B (TIME PERIOD IN YEARS)	AFTER CRASH FREQUENCY N_A (TIME PERIOD IN YEARS)
Leonard Street and College Avenue	40.4 (1)	31 (3.92)
Burton Street and Kalamazoo Avenue	37.5 (1)	48 (2.42)
Burton Street and Breton Avenue	45.0 (1)	80 (2.42)
Eastern Avenue and Franklin Street	33.0 (1)	33 (1.67)
Seven Mile Road and Ryan Road	51.0 (1)	165 (5.25)
Hubbell Road and Puritan Road	19.6 (1)	71 (4.83)
Wyoming Road and Lyndon Road	40.5 (1)	15 (0.75)
Schaefer Highway and Seven Mile Road	33.4 (1)	12 (0.67)

$\chi^2_{calculated} = 72.95$ $\chi^2_{critical} = 14.067$ at $\alpha = 0.05$ and 7 degrees of freedom

The results of the Chi-Square analysis indicated that $\chi^2_{calculated}$ is greater than the $\chi^2_{critical}$ at 95 percent level of confidence, and thus the expected crash frequencies are significantly different from the actual 'after' crash frequencies for the selected test sites in Detroit and Grand Rapids.

Paired t-Test for Crash Rates (B&A with Control Study)

The Paired t-test was also used to test the significance of the 'before and after with control' study for differences in the group means and variances of the expected crash rate without treatment, as compared to the actual 'after' crashes. The calculations of the crash rates used in this analysis are shown in Table 12.

Table 12. Crash Rates Used in the Paired t-Test Calculations for the 'Before and After with Control' Study

INTERSECTIONS IN THE CITY OF GRAND RAPIDS	EXPECTED CRASH RATE* WITHOUT TREATMENT	ACTUAL 'AFTER' CRASH RATE*
Leonard Street and College Avenue	2.82	0.53
Burton Street and Kalamazoo Avenue	2.82	1.48
Burton Street and Breton Avenue	1.90	1.39
Eastern Avenue and Franklin Street	3.38	2.01
Seven Mile Road and Ryan Road	4.95	3.05
Hubbell Road and Puritan Road	2.41	1.79
Wyoming Road and Lyndon Road	3.09	1.52
Schaefer Highway and Seven Mile Road	2.22	1.22

* Crashes per million entering vehicles (MEV)

Mean of expected crash rate without treatment = 2.95 crashes/MEV

Mean of 'after' crash rate = 1.63 crashes/MEV

Variance of the expected crash rate without treatment = 0.88

Variance of the 'after' crash rate = 0.52

$t_{calculated} = 6.14$; $t_{critical} = 1.895$ at $\alpha = 0.05$ and 7 degrees of freedom

Since $t_{calculated}$ is greater than $t_{critical}$ at 95 percent level of confidence, there is a significant difference in the group mean and the variance of the expected crash rate without treatment and the 'after' crash rate.

The results of these three statistical analyses (Poisson test of significance, Chi-Square test and Paired t-test) indicated that the <u>countermeasures installed at the test site in comparison to those sites where no improvements were made, are effective in reducing the targeted crash types. The results also correspond to the results of the 'before and after' studies.</u>

7.0 EMPIRICAL BAYES METHOD

The purpose of applying the Empirical Bayes (EB) method in this study is to identify if regression to the mean phenomena exist at the study site, and if so, to what extent they affect the results of the 'before and after' evaluation study.

The EB method was used in this analysis to account for regression to the mean bias that may be associated with 'before and after' evaluations, especially when the locations being evaluated were selected based on their high traffic crash history *(10)*. This method is based on the premise that traffic crashes at the study sites are not the only measure used to assess its safety; crash data at similar sites, as well as traffic volumes and/or other operational parameters.

According to Hauer, the EB method increases the precision of estimation and corrects for the regression to the mean bias *(10)*. In this method, traffic crash data at the test site and the crash experience expected at similar sites, are used along with weighted factors to calculate the expected number of crashes at the test sites without the applied treatment. The EB methodology used by Persaud, Retting, et al. *(11)* in an evaluation study for converting standard intersections to roundabouts is applied here. Specifically, the expected number of crashes (*B*) that would have occurred in the after period had the treatments <u>not</u> been implemented is based on the following *(11)*:

1. "The annual number of crashes (*P*) that would be expected at intersections with traffic volumes and other characteristics similar to the one being analyzed" is estimated based on a regression model. *(11)*

2. Traffic crash frequency at the test site in the 'before' period is combined with the estimate of (*P*) to determine the expected annual number of crashes (*m*) at the test site before treatment": *(11)*

$$m = w_1(X) + w_2(P) \qquad \text{[Equation 1]}$$

Where, the weights w_1 and w_2 are "estimated from the mean and variance of the regression estimate as" *(11)*

$w_1 = P / (k + nP)$ [Equation 2]

$w_2 = k / (k + \mathrm{n}P)$ [Equation 3]

Where, $k = P^2 / Var\ (P)$ [Equation 4]

and k is a "constant for a given model and is estimated from the regression calibration process" *(11).*

Substituting the values of w_1 and w_2 into Equation 1 and dividing each term by P, gives:

$$m = (k + x) / (k / P + y)$$

3. To estimate B, adjustments are then made to account for volume changes between the 'before' and 'after' periods, as well as for the length of time the 'after' data was accumulated. To adjust for volume changes, the expected annual number of crashes in the 'before' period is multiplied by R, "the ratio of the annual regression predictions for the 'before' and 'after' periods" *(11)*.

   $m_a = R \times m_b$,

   Where, $R = P_a/P_b$

   To estimate B, the number of crashes that would have occurred in the after period, had the safety treatments not been implemented, m_a is multiplied by y_a, the length of the 'after' period in years.

   $B = m_a \times (y_a)$

4. The variance of B is given by:

$$\text{Var (B)} = \frac{(m_b) \times (R \times y_a)^2}{[(k/P) + y_b]}$$

In order to estimate the safety effects, the Index of Effectiveness (θ) may be used *(11)* and can be calculated according to the following equation:

$$\theta = \frac{(A/B)\ (\Sigma A/\Sigma B)}{\{1 + [\ Var(B)/(\Sigma B)^2]\}}$$

Where, A = number of crashes reported in the after period

The percent change in crashes can be calculated as 100 (1- θ).

In order to demonstrate how the results of the 'before and after' study compare with the results based on the Empirical Bayes estimate, eight intersections in the cities of Detroit and Grand Rapids were selected for analysis. These sites selected had crash reductions greater than 35 percent, for total, injury, and the targeted crash types, based on the 'before and after' studies and the annual average total crash frequency in the 'before' period at each intersection was greater than 20 crashes per year. These were considered candidate locations where regression to the mean effects may be observed. These sites in the cities of Detroit and Grand Rapids are the same test sites in which additional analyses were performed (Sections 6.4, 6.5 and 6.6) as presented earlier in this report. The following provides details of the Empirical Bayes estimate, analysis and results.

7.1 Regression Model

In order to calculate an Empirical Bayes estimate, two-regression models, based on traffic crash frequency and traffic volume data at a number of similar intersections used as control sites in the cities of Detroit and Grand Rapids were used. The following models were considered in this analysis based on past research conducted by others as noted by the references:

Crashes/year = $\alpha(\text{ADT}_{\text{Total Intersection}})^{\beta}$ *(11)*

Crashes/year = $\alpha\ (\text{ADT}_{\text{Total Intersection}})^{\beta 1}$ (Proportion of minor street ADT to the Total intersection ADT)$^{\beta}$ *(11)*

Crashes/year = $\alpha(\text{ADT major Street})^{\beta 1}$ $(\text{ADT Minor Street})^{\beta 2}$ *(12)*

The data used in the regression models consisted of 21 intersections in the City of Grand Rapids and 55 intersections in the City of Detroit. Two different regression models were used for each city based on data from the two cities included in this evaluation study. The intersections were randomly selected from a larger group of intersections since traffic crash data and volume data were available at these sites. It is important to note that the similar sites used in this analysis are in the same geographic area as the test sites, and as such a large sample group is not necessarily required. By selecting similar sites in the same geographic area such as a city, driver behavior and other influences were somewhat controlled, thereby reducing the variability and sample size requirements. It is important to note that other researchers in the past have used data from intersections in other states, and even in another country to develop prediction model equations *(11).* In these studies, larger sample sizes were required to account for variability of other uncontrollable influences.

Grand Rapids Regression Model:

A group of 21 similar intersections were used as a control group in the City of Grand Rapids. These sites were all four-legged signalized intersections that were not treated with safety improvements. The average daily traffic volume for the similar sites ranged from 20,000 to 70,000 vehicles per day. This group of similar intersections was located in close proximity to the test intersections and thus, driver characteristics through the intersections were <u>not</u> expected to vary measurably. Traffic crash data for each of the sites was available for a range of one to four years. The traffic crash experience at the similar sites ranged from 10 to 55 crashes per year, with a mean of 28 crashes per year among the 21 sites. The following is the regression model (assuming a lognormal distribution), which produced the best estimate of crashes based on total entering intersection volumes and proportion of the minor road volumes to the total intersection volumes.

$$P_{GR} = 4.14 \times 10^{-5} (ADT_{\text{intersection}})^{1.222} (ADT_{\text{proportion of minor street}})^{-0.461}$$

$$(R^2 = 0.67)$$

The coefficient of determination (R^2) value obtained is 0.67 and the correlation between the two independent variables is reasonably low.

Detroit Regression Model:

A total of 55 similar intersections (four-leg intersections) were used as the control group in the City of Detroit. These intersections were selected in a similar manner to those selected in Grand Rapids. The average daily traffic volumes ranged from 13,000 to 63,000 vehicles per day. Traffic crash data was available for three years for each of the sites. The crash experience ranged from approximately 9 to 70 crashes per year, with a mean of 34 crashes per year among the 55 sites. The following is the resulting regression model:

$$P_{Detroit} = 3.2*10^{-3}*(ADT_{intersection})^{0.921}*(ADT_{Proportion\ of\ Minor\ Street})^{0.361}$$

$(R^2 = 0.66)$

Details of the regression models are included in Appendix X.

Bauer and Harwood *(13)* studied regression models to determine a relationship between crash frequencies and volume, geometric design, and other factors, using a lognormal, Poisson, and negative binomial regression analysis. The authors state that the lognormal regression model is a logical and appropriate choice for modeling four-legged urban signalized intersection crashes, since these intersections typically experience high crash frequencies and follow this type of distribution. Bauer and Harwood presented a regression model for four-legged signalized intersections based on nineteen explanatory variables, and two years of traffic crashes data at 1,309 intersections. The final lognormal regression model resulted in nine significant explanatory variables with an R^2 value of 0.25 for predicting total crashes. The authors also stated "the regression models of the relationship between accidents and intersection geometric design, traffic control and traffic volume variables were found to explain between 16 and 30 percent of the variability in the accident data. However, most of that variability was explained by the traffic volume variable considered (major road and cross road average daily traffic)" *(13).*

Thus, the research conducted by Bauer and Harwood supports the use of the lognormal regression model developed in this study for the RIDP. Additionally, the R^2 values of 0.67 and 0.66 show a reasonable correlation between the crash frequencies, intersection volume and proportion of minor street volumes to the total intersection volumes. The regression coefficients in both the Detroit and Grand Rapids models were significant at 94 percent and higher confidence level.

7.2 Empirical Bayes Estimate of Expected Traffic Crashes Without Treatment

Estimates of the expected crash frequencies without treatment were determined for the eight sample sites; four intersections in the City of Grand Rapids and four sites in the City of Detroit. These sites are the same test sites in which addition analyses were performed (Sections 6.4, 6.5 and 6.6) as presented earlier in this report.

Table 13 shows the details of the analysis of the eight intersections using EB method for the cities of Detroit and Grand Rapids. Table 14 shows the results of the EB analysis, as well as percent reductions based on the 'before and after' and 'before and after with control' studies.

Table 13. Data Used in the Empirical Bayes Estimate Analysis for the Eight Study Sites

Location	Test Site	Intersection ADT (vehicles per day)		Proportion of Minor Street to Total Intersection ADT		Before Crash Frequency Xb	Before Period Yb	After Crash Frequency Xa	After Period Ya	Pb	mb	Pa	R	ma	Bayesian Estimates		Unbiased Index of Effectiveness	Percent Reduction (Bayesian Estimates for Total Crashes)
		Before	After	Before	After										B	Var (B)		
City of Detroit	Seven Mile and Ryan	25,529	28,249	0.40	0.40	204	3	165	5.25	26.33	65.34	28.90	1.10	71.73	376.6	677.3	0.4389	56.11%
	Hubbell and Puritan	23,143	22,529	0.46	0.46	105	3	71	4.83	25.30	34.36	24.68	0.98	33.52	161.9	237.4		
	Wyoming and Lyndon	35,372	36,000	0.20	0.20	41	0.75	15	0.75	27.68	49.11	28.13	1.02	49.91	37.4	30.2		
	Schaefer and Seven Mile	48,428	41,164	0.44	0.40	25	0.67	12	0.67	49.14	38.97	40.88	0.83	32.42	21.7	15.5		
							Sum =	**263**						**Sum =**	**597.6**	**960.4**		
City of Grand Rapids	Leonard and College	30,386	39,272	0.29	0.31	50	2	31	3.92	22.01	24.73	31.11	1.41	34.95	137.0	344.8	0.4544	54.56%
	Burton and Kalamazoo	37,000	36,518	0.42	0.47	72	2	48	2.42	23.61	34.94	23.50	1.00	34.77	84.2	92.7		
	Burton and Breton	60,857	64,814	0.45	0.45	114	2	80	2.42	42.00	56.25	48.32	1.15	64.71	156.6	207.1		
	Eastern and Franklin	27,572	26,830	0.35	0.35	52	2	33	1.67	17.92	25.11	18.47	1.03	25.87	43.2	33.1		
							Sum =	**192**						**Sum =**	**420.9**	**677.6**		

Table 14. Percent Reductions in Total Crashes Based on the 'Before and After' and Before and After with Control' Studies and the Empirical Bayes Estimate Analysis for the Eight Study Sites

Selected Group of Test Sites	Percent Reduction ('Before and After' Study for Total Crashes)	Percent Reduction ('Before and After' With Control Study for Total Crashes)	Percent Reduction (Bayesian Estimates for Total Crashes)
Selected Sites in the City of Detroit	56.92%	41.81%	56.11%
Selected Sites in the City of Grand Rapids	44.03%	48.39%	54.56%
Detroit and Grand Rapids Sites Combined	**51.44%**	**45.22%**	**55.40%**

The estimated crash reductions as summarized in the last two columns in Table 13 provide two measures of the safety effects, based on the EB method. The first is the index of effectiveness (θ) which is approximately equal to the ratio of the number of crashes occurring after safety treatments were installed, to the number of expected crashes in the 'after' period had the treatments not been installed. *(11)* The second measure is the conventional percent reduction in crashes. The EB method estimated a 56.11 percent reduction for the sample test intersections in the City of Detroit and 54.56 percent reduction for the sample test intersections in the City of Grand Rapids. In Detroit, the percent reduction using the EB method is essentially the same as the percent reduction obtained using the B&A study for the sample test intersections, and is higher than the results of the B&A with control study. In Grand Rapids, the percent reduction in total crashes using the EB method is higher than that obtained using both the B&A study and B&A with control study for the same sample test sites.

For the sample test intersections in both cities combined, an overall 55 percent reduction in crashes resulted from the EB method, a 45 percent reduction from the B&A with control study, and a 51 percent reduction was obtained from the B&A study.

Therefore, the overall results of the EB method performed for the sample study intersections are similar to the results of the 'before and after' study. It is important to note that these intersections were selected for additional analysis using the EB method, since they were candidate locations where regression to the mean effects may occur. It can be concluded that through the EB analysis, in general, regression to the mean effects were not identified at the study sites, since the overall percent reductions based on the EB method were similar to those based on the 'before and after' study. <u>Thus, the 'before and after' percent reductions for the test sites can be considered reasonably unbiased and represent realistic impacts of the improvements.</u>

8.0 EVALUATION OF COUNTERMEASURES

A series of evaluations were performed to determine the effectiveness of specific countermeasures. This was done by forming groups of intersections where similar countermeasures were installed and comparing the 'before' and 'after' crash experience for the group of sites combined. The following countermeasures were evaluated:

– Upgrading 8-inch signal lenses to 12-inch lenses and installing all-red intervals.
– Installing exclusive left-turn lanes.
– Installing exclusive left-turn lanes and an exclusive (permitted/protected) left-turn phase.
– Installing an exclusive left-turn phase.

The results of the 'before' and 'after' study of the implemented countermeasures is shown in Table 15. The intersections included in each of the groups, as well as their 'before' and 'after' crash frequencies for each of the tested countermeasures are included in Appendix XI.

Table 15. 'Before and After' Evaluation for Groups of Similar Safety Improvement Projects

TYPE OF IMPROVEMENTS	TOTAL CRASHES			INJURY CRASHES			TARGETED CRASH TYPE		
	Annual Average Crash Frequency ('Before')	Annual Average Crash Frequency ('After')	% Reduc-tion	Annual Average Crash Frequency ('Before')	Annual Average Crash Frequency ('After')	% Reduc-tion	Annual Average Crash Frequency ('Before')	Annual Average Crash Frequency ('After')	% Reduc-tion
12-inch signal lenses and all-red intervals (40 sites)	640.3	460.0	28%*	172.8	107.9	38%*	140.8	38.6	72%*
							Right-angle crashes		
Exclusive left-turn lanes only (8 sites)	166.8	96.9	42%*	57.6	26.7	54%*	31.9	14.4	55%*
							Left-turn head-on crashes		
Exclusive left-turn lanes and left-turn phase (11 sites)	416.5	268.9	35%*	120.7	56.2	53%*	91.6	29.1	68%*
							Left-turn head-on crashes		
Exclusive left-turn phase only (10 sites)	305.8	216.4	29%*	83.2	44.3	47%*	56.6	18.6	67%*
							Left-turn head-on crashes		

9.0 ECONOMIC ANALYSIS

Economic analyses were performed as a part of this study in order to determine the economic effectiveness of the implemented safety improvement projects. This analysis was performed for those test sites in which cost data for the implementation of the safety improvements was available. The associated benefits at these project sites were estimated based on the reduction of crashes experienced after the safety improvements were implemented. The Equivalent Uniform Annual Benefit/Equivalent Uniform Annual Cost (EUAB/EUAC) method was used in this analysis.

An economic analysis of benefits, from a societal perspective, was conducted using the comprehensive crash costs based on recent National Safety Council (NSC) cost data. These costs essentially identify a society's willingness to pay to prevent crashes and injuries. According to the NSC Year 2001 data the average cost of an injury crash is $35,300.00 for a property damage crash is $6,500.00 and for a fatal crash is $1,040,000. The economic analysis was performed corridor-wise and also for the isolated intersections.

The following assumptions were used in the economic analyses:

- Annual maintenance cost = $500.00/location
- Inflation rate = 0
- Discount rate = 6%
- Economic life = 15 years
- Salvage value = $0

Please note that an annual maintenance cost of $500.00 per intersection was assumed as a part of this analysis to account for increases in the total annual maintenance cost, which are directly related to the improvements. Such additional maintenance costs may accrue due to increased restriping costs for left-turn lanes, increased cost for larger signal lens replacement and others.

The equivalent uniform costs and benefits, B/C ratio and net present value for the study corridors and intersections are summarized in the Table 16.

Table 16. Result of the Economic Analysis

COMPLETED RIDP INTERSECTIONS/ CORRIDORS	CONSTRUCTION COST	TOTAL ANNUAL COST (EUAC)	TOTAL ANNUAL BENEFIT (EUAB)	B/C RATIO	NET PRESENT VALUE
Woodward Avenue Corridor (33 intersections)	$2,330,000	$256,404	$2,823,010	11:1	$24,927,524
Grand River Avenue Corridor (8 intersections)	$1,200,000	$127,556	$113,750	0.9:1	-$134,081
Wyoming Road Corridor (5 intersections)	$298,000	$33,183	$1,241,880	37:1	$11,739,167
Division Avenue Corridor (9 intersections)	$380,000	$43,626	$836,050	19:1	$7,696,221
Burton Street and Eastern Avenue Corridors (17 intersections)	$670,000	$77,485	$2,171,700	28:1	$20,339,537
Seven Mile Road at Ryan Road	$36,100	$4,217	$606,360	144:1	$5,848,163
Seven Mile Road at John R Road	$35,200	$4,124	$479,110	116:1	$4,613,179
Hubbell Road at Puritan Road	$30,300	$3,620	$391,150	108:1	$3,763,790
Schoolcraft Road at Evergreen Road	$272,000	$28,506	$253,770	9:1	$2,187,821
Harper Avenue at Cadieux Avenue	$60,000	$6,678	$97,240	15:1	$879,563
Harper Avenue at Dickerson Road	$60,000	$6,678	$97,630	15:1	$883,351
I-94 Service Drives at Cadieux Avenue	$100,000	$10,796	$94,350	9:1	$811,495
Schaefer Road at McNichols Road	$25,000	$3,074	$211,800	69:1	$2,027,198
Schaefer Road at Seven Mile Road	$25,000	$3,074	$299,550	97:1	$2,879,448
Leonard Street at College Avenue	$65,000	$7,193	$189,560	26:1	$1,771,198
TOTAL (82 intersections)	**$5,646,000**	**$616,214**	**$9,906,910**	**16:1**	**$90,233,574**

As shown in Table 16, the overall benefit to cost ratio for the improvement project is 16 to 1, which indicates that the accrued benefits in dollar value is higher than the implemented improvement costs. On a corridor and intersection basis, all the locations had B/C ratios that exceeded 1, except for the Grand River corridor (0.9 to 1).

10.0 SUMMARY AND CONCLUSIONS

As a part of the AAA Michigan Road Improvement Demonstration Program, improvements have been implemented at 172 intersections and the evaluation study is based on the results of the crash experiences of 85 of these intersections.

Of the 85 intersections, 57 intersections are located in the City of Detroit and 28 are located in the City of Grand Rapids. In Detroit, three corridors were evaluated including Woodward Avenue, Wyoming Avenue and Grand River Avenue, as well as eleven isolated intersections. In Grand Rapids, three corridors were evaluated including Burton Street, Division Avenue and Eastern Avenue, as well as two isolated intersections.

The evaluation plan consisted of 'before and after' studies performed for all the test intersections and corridors, as well as 'before and after with control' studies and the Empirical Bayes method applied to a sample of intersections with high crashes during the 'before' period. The 'before and after with control' and the Empirical Bayes method were used to debias the 'before and after' studies from regression to the mean effects.

In addition, several statistical tests were used to evaluate the effectiveness of the crash reductions, including the Poisson test for crash frequencies, the Chi-Square test and the Paired t-Test.

<u>The results of the rigorous analyses performed for the sample of intersections indicate that the evaluation results based on the 'before and after' study are unbiased, valid and statistically supported.</u>

The percent reductions for total, injury and total targeted crash types for each of the corridors and the isolated intersections combined are shown in the following table.

Percent Reductions Based on the B&A Study for the Michigan RIDP Intersections and Corridors

CORRIDORS/ INTERSECTIONS	TOTAL	INJURY	TARGETED CRASH TYPES	
			ANGLE	LEFT-TURN HEAD-ON
Woodward Avenue Corridor (33 signalized intersections)	33%	46%	76%	-40% (Increase) (Not targeted)
Grand River Avenue Corridor (8 signalized intersections)	6%	-26% (Increase)	-14% (Increase)	16%
Wyoming Road Corridor (5 signalized intersections)	41%	56%	52%	76%
Burton Street Corridor (8 signalized intersections)	33%	44%	62%	58%
Division Avenue Corridor (9 signalized intersections)	12%	38%	39%	58%
Eastern Avenue Corridor (9 signalized intersections)	33%	60%	72%	54%
Isolated Intersections (11 signalized intersections)	35%	44%	72%	61%
OVERALL RIDP	**30%**	**41%**	**63%**	**46%**

The evaluation for the intersections of Linwood Avenue and Davison Avenue in the City of Detroit and Michigan Street and Ottawa Avenue in the City of Grand Rapids were not performed, since in one instance significant land use changes were made during the ‘after’ period and a safety treatment previously installed was removed. In the other case, the critical recommended improvements were not installed at all.

The following is a summary of the findings and conclusions of this evaluation study.

7. In the AAA Michigan RIDP, the annual average total crash frequencies for the corridors and isolated intersections included in the evaluation study combined were reduced by 30 percent, from 1,781 crashes per year in the 'before' period to 1,249 crashes per year in the 'after' period. Likewise, the injury crashes were reduced by 41 percent, from 506 crashes per year in the 'before' period to 299 crashes per year in the 'after' period.

8. This reduction in crashes demonstrates that the countermeasures implemented at the intersections and corridors in the Cities of Detroit and Grand Rapids were effective in reducing the targeted crashes thereby, reducing the total number of crashes at these locations. The general countermeasures that were aimed at mitigating angle and injury crashes include the following:
   - Installing all-red intervals with lengths calculated as per the ITE guidelines.
   - Relocating signal heads to the center of the roadway oriented over the travel lanes to improve visibility.
   - Replacing the 8-inch signal lenses with 12-inch signal lenses, in spite of the speed limit on the study roadways being lower than the recommended speed limit for installing 12-inch signal heads.
   - Installing of back plates on the traffic signals to improve visibility and to reduce sun glare (Burton Street corridor, Grand Rapids).

   The countermeasures for alleviating left-turn head-on and injury crashes included the following:
   - Installing secondary post mounted left-turn signals.
   - Installing exclusive left-turn lanes and/or permitted/protected left-turn signal phases, when needed.

   It is important to note that when implementing permitted/protected left-turn signal phases, the guidelines used to justify the additional phase were less conservative, as compared to common practice in Michigan.

9. The ‘before’ and ‘after’ study of the groups of intersections with similar countermeasures resulted in the following statistically significant percent reductions:
   - Installation of all-red intervals and upgrading signal lenses to 12-inch diameters.
     - 72% reduction in angle crashes.
   - Installation of exclusive left-turn lanes only.
     - 55% reduction in left-turn head-on crashes.
   - Installation of exclusive left-turn lanes and phases.
     - 68% reduction in left-turn head-on crashes.
   - Installation of exclusive left-turn phase only.
     - 67% reduction in left-turn head-on crashes.

10. The isolated intersections which had a very high crash frequency during the ‘before’ period were also tested for the regression to the mean effects. No substantial regression to the mean effects was found.

11. In order to demonstrate that the ‘before and after’ study results are realistic in comparison to the results of other methods, ‘before and after studies with control sites’ and Empirical Bayes analyses were performed at selected intersections in City of Grand Rapids and City of Detroit for which suitable control sites were identified. Three statistical tests were performed to determine if significant crash reductions were observed at the test sites. The significant results of Poisson test, Chi-Square test and Paired t-test helped to conclude that the implemented countermeasures were effective in reducing the targeted crashes.

12. Economic analysis was performed to determine the benefit-cost ratio at all the intersections and corridors where improvements were made. The overall benefit-cost ratio for all the intersections and corridors combined, indicated that the accrued benefits are higher in dollar value than the incurred costs and resulted in the benefit-cost ratio of 16 to 1.

Based on the effectiveness evaluation of the treated sites, the specific safety improvements were successful in reducing the targeted crash types, thereby, reducing the total and injury crashes at these locations.

11.0 ACKNOWLEDGEMENTS

The authors thank Michigan Office of Highway Safety Planning, AAA Michigan, the City of Detroit and the City of Grand Rapids for assistance and continued support for this study. The authors would also like to personally thank Richard Miller and Jeff Bagdade for their continued assistance and technical support.

12.0 REFERENCES

1. Michigan Department of Transportation in conjunction with the Michigan Department of State Police, "Michigan Manual of Uniform Traffic Control Devices" (MMUTCD), 1994 Edition.

2. ITE Technical Council Task Force 4TF-1, "Determining Vehicle Signal Change and Clearance Intervals" Informational Report, Washington, D.C., August 1994.

3. Datta, T.K., Sharma, S., Schattler, K., and Ghosh, S., "Investigation of the Quality of Traffic Crash Data in Michigan", Michigan Department of Transportation, December 2002.

4. Persaud, B.N. and Hauer, E., "Comparison of Two Methods for Debiasing Before-and-After Accident Studies", ***Transportation Research Record 975***, Washington, D.C., 1984.

5. "Accident Research Manual", DOT-FH-11-9424, U.S. Department on Transportation, Federal Highway Administration, Washington D.C., 1980.

6. Datta, T.D., Feber, D., Schattler, K. and Datta, S., "Effective Safety Improvement Through Low-Cost Treatments", ***Transportation Research Record 1734***, Transportation Research Board-National Research Council, Washington, D.C., 2000.

7. "Highway Safety Evaluation Procedural Guide" (FHWA-TS-81-219), U.S. Department of Transportation, Federal Highway Administration, March 1981.

8. "Highway Safety Improvement Program" (FHWA-TS-81-218), Federal Highway Administration, 1981.

9. Tanner, J.C., "A Problem in the Combination of Accident Frequencies." ***Biometrics 45***, 1958.

10. Hauer, E., "Estimating Safety by the Empirical Bayes Method: A Tutorial", *Journal of the Transportation Research Board*, ***Transportation Research Record 1784***, Washington, D.C., 2002.

11. Persaud, B.N., Retting, R., Garder, P.E, Lord, D., "Safety Effect of Roundabouts Conversion in the United States Empirical Bayes Observational Before–After Study" ***Transportation Research Record 1751***, Transportation Research Board-National Research Council, Washington, D.C., 2001.

12. Vogt, A. and Bared, J., "Accident Model for Two-Lane Rural Segments and Intersections", ***Transportation Research Record 1635***, Transportation Research Board-National Research Council, Washington, D.C., 1998.

13. Bauer, K.M. and Harwood, D.W., "Statistical Models of At–Grade Intersection Accident-Addendum", Federal Highway Administration Report FHWA-RD-99-094, March 2000.

APPENDIX I – LISTING OF COUNTERMEASURES INSTALLED AT THE STUDY INTERSECTIONS/CORRIDORS

		Completed AAA RIDP Intersections	Countermeasures implemented at the Study Intersections					
			12" Diameter Signal Lens	Left-Turn Lane	Left-Turn Phase	Low Level	All-Red Interval	Improved Signal Placement
WOODWARD CORRIDOR	1.	Woodward at Sibley/Adelaide	X				X	X
	2.	Woodward at Charlotte	X				X	X
	3.	Woodward at Stimson/Eliot	X				X	X
	4.	Woodward at Mack/MLK	X				X	X
	5.	Woodward at Parsons	X				X	X
	6.	Woodward at Alexandrine	X				X	X
	7.	Woodward at Canfield	X				X	X
	8.	Woodward at Forest	X				X	X
	9.	Woodward at Warren	X				X	X
	10.	Woodward at Fansworth/Putnam	X				X	X
	11.	Woodward at Kirby	X				X	X
	12.	Woodward at Palmer	X			X	X	X
	13.	Woodward at Antionette/Medbury	X				X	X
	14.	Woodward at Baltimore	X				X	X
	15.	Woodward at Milwaukee	X				X	X
	16.	Woodward at Bethune	X				X	X
	17.	Woodward at Seward/Marston	X				X	X
	18.	Woodward at Euclid	X				X	X
	19.	Woodward at Hazelwood/Holbrook	X				X	X
	20.	Woodward at Clairmont/Owen	X				X	X
	21.	Woodward at Chicago/Arden Park	X				X	X
	22.	Woodward at Calvert/Trowbridge	X				X	X
	23.	Woodward at Tuxedo/Tennyson	X				X	X
	24.	Woodward at Courtland	X				X	X
	25.	Woodward at Glendale/McLean	X				X	X
	26.	Woodward at Buena Vista	X			X	X	X
	27.	Woodward at Gerald	X				X	X
	28.	Woodward at Manchester	X				X	X
	29.	Woodward at Sears/Ford	X				X	X
	30.	Woodward at Pilgrim/Ferris	X				X	X
	31.	Woodward at Merrill Plaisance	X			X		
	32.	Woodward at Seven Mile	X					
	33.	Woodward at State Fair	X					
GRAND RIVER CORRIDOR	34.	Grand River at Burt	X					
	35.	Grand River at Evergreen	X			X		
	36.	Grand River at Lahser	X			X		X
	37.	Grand River at McIntyre	X			X		
	38.	Grand River at McNichols	X			X		
	39.	Grand River at Outer Drive	X			X		
	40.	Grand River at Patton	X			X		
	41.	Grand River at Warwick	X			X		
WYOMING CORRIDOR	42.	Wyoming at Curtis	X	X		X	X	
	43.	Wyoming at Lyndon		X	X	X	X	
	44.	Wyoming at Puritan	X	X	X	X	X	
	45.	Wyoming at Schoolcraft		X	X	X	X	
	46.	Wyoming at Seven Mile			X	X		
ISOLATED INTERSECTIONS	47.	Seven Mile at Ryan	X	X	X	X	X	
	48.	Seven Mile at John R	X	X	X	X	X	
	49.	Hubbell at Puritan	X	X		X	X	
	50.	Schoolcraft at Evergreen	X	X			X	
	51.	Davison at Linwood	X	X	X	X		X
	52.	I-94 Service Drives at Cadieux	X			X	X	
	53.	Dexter at Davison	X				X	
	54.	Schaefer at McNichols			X	X		
	55.	Schaefer at Seven Mile			X	X		
	56.	Harper at Cadieux	X		X	X	X	
	57.	Harper at Dickerson	X				X	

		Completed AAA RIDP Intersections	Countermeasures Implemented at the Study Intersections							
			12" Diameter Signal Lens	Left-Turn Lane	Left-Turn Phase	Low Level	All-Red Interval	Additional Overheads	BOX Span	Back Plate
BURTON CORRIDOR	1.	Burton at Breton	X			X	X		X	X
	2.	Burton at Buchanan	X		X	X	X		X	X
	3.	Burton at Jefferson	X			X	X		X	X
	4.	Burton at Kalamazoo	X		X	X	X		X	X
	5.	Burton at Madison	X	X	X	X	X		X	X
	6.	Burton at Plymouth	X	X	X	X	X		X	X
	7.	Burton at Raybrook	X			X	X		X	X
	8.	Burton at Sylvan	X			X	X		X	X
DIVISION CORRIDOR	9.	Division at Cherry	X				X	X		
	10.	Division at Weston	X				X	X		
	11.	Division at Wealthy	X		X		X		X	
	12.	Division at Oakes	X				X	X		
	13.	Division at Hall	X	X	X	X	X			
	14.	Division at Franklin	X	X	X		X		X	
	15.	Division at Delaware	X	X			X	X	X	
	16.	Division at Cottage Grove	X	X			X			
	17.	Division at Burton	X	X	X		X		X	
EASTERN CORRIDOR	18.	Eastern at Cherry	X	X		X	X		X	
	19.	Eastern at Hall	X			X	X		X	
	20.	Eastern at Oakdale	X	X		X	X		X	
	21.	Eastern at Alger	X	X		X	X		X	
	22.	Eastern at Burton	X			X	X			
	23.	Eastern at Lake	X	X	X	X	X		X	X
	24.	Eastern at Sherman	X	X		X	X		X	
	25.	Eastern at Wealthy	X	X	X	X	X		X	
	26.	Eastern at Franklin	X	X	X	X	X		X	
	27.	Leonard at College	X	X			X			
	28.	Michigan at Ottawa		X			X			

APPENDIX II – SUMMARY OF THE ‘BEFORE AND AFTER’ CRASH ANALYSIS FOR THE WOODWARD AVENUE CORRIDOR INTERSECTIONS IN THE CITY OF DETROIT, MICHIGAN

Woodward Avenue Corridor,

City of Detroit and Highland Park

Before Data and After Data: UD-10 Forms

PREDOMINANCE CRASH TYPES	BEFORE AND AFTER STUDY				POISSON TEST OF SIGNIFICANCE @ alpha = 0.05
	'BEFORE' CRASHES	'AFTER' CRASHES	DIFFERENCE		
	12-Month Average of Before Data	12-Month Average of After Data	'Before'- 'After'	Reduction	
Rear End	118.5	93.7	24.8	21%	Yes
Angle (Intersection)	116.0	28.1	87.9	76%	Yes
Left-Turn Head-On	32.5	45.5	-13.0	-40%	Yes
Sideswipe	93.5	54.8	38.7	41%	Yes
Other	109.0	91.0	18.0	16%	Yes
TOTAL	**469.5**	**313.1**	**156.4**	**33%**	**Yes**
Injury	137.5	74.8	62.7	46%	Yes

Results of 'Before' and 'After' Study for Total and Targeted Crashes for Intersections Along Woodward Avenue Corridor

INTERSECTIONS ALONG WOODWARD AVENUE CORRIDOR	TOTAL CRASHES		INJURY CRASHES		ANGLE CRASHES	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
Sibley/Adelaide	1.0	2.5	0.0	1.1	0.0	0.4
Charlotte	5.5	2.1	1.5	0.7	0.0	0.0
Eliot/Stimson	2.0	1.4	0.0	0.4	0.0	0.4
Mack	19.0	25.8	4.0	5.6	5.5	2.8
Parsons	4.0	5.6	0.5	1.4	0.0	0.4
Alexandrine	14.5	11.6	2.5	1.4	1.5	0.7
Canfield	14.0	7.8	3.5	1.4	3.5	0.7
Forest	29.0	18.0	5.5	3.9	14.0	1.4
Warren	51.0	38.5	11.0	7.8	11.5	6.0
Putnam	16.0	9.5	3.0	0.4	0.0	0.0
Kirby	13.0	5.6	4.5	0.7	0.5	0.0
Palmer	13.5	8.8	2.5	1.8	4.0	1.4
Antionette/Medbury	3.5	1.1	1.5	1.1	1.5	0.4
Baltimore	12.5	7.8	4.0	1.8	0.5	0.0
Milwaukee	24.0	10.2	7.0	2.1	12.0	0.7
Bethune	6.5	6.0	2.0	2.1	2.0	0.0
Seward/Marston	8.5	6.0	3.0	1.4	1.0	0.4
Euclid	14.0	6.7	4.5	1.1	2.0	0.7
Hazelwood/ Holbrook	10.5	7.4	2.5	2.5	2.5	1.8
Clairmount/ Owen	16.0	7.4	6.0	1.8	6.5	0.4
Chicago/ Aden Park	12.0	3.9	4.5	0.0	2.0	0.4
Calvert/Trowbridge	8.5	4.2	1.0	0.7	1.5	0.0
Tuxedo/ Tennyson	1.0	2.5	0.0	0.0	0.0	0.0
Courtland	1.0	1.5	0.0	0.0	1.0	0.5
Glendale/McLean	15.0	21.0	4.0	7.0	1.0	1.0
Buena Vista	4.0	7.0	1.0	3.0	1.0	0.5
Gerald	2.0	6.0	1.0	0.5	0.0	0.0
Manchester	38.0	17.5	17.0	6.0	18.0	2.0
Sears/Ford	20.0	11.0	10.0	5.0	4.0	1.0
Ferris/Pilgrim	9.0	8.0	2.0	2.0	3.0	0.5
Merrill Plaisance	6.5	0.9	3.5	0.0	3.5	0.0
Seven Mile	46.0	24.0	15.5	6.5	8.5	3.7
State Fair	28.5	15.7	9.0	3.7	4.0	0.0
TOTAL	**469.5**	**313.1**	**137.5**	**74.8**	**116.0**	**28.1**

APPENDIX III – SUMMARY OF THE ‘BEFORE AND AFTER’ CRASH ANALYSIS FOR THE GRAND RIVER AVENUE CORRIDOR INTERSECTIONS IN THE CITY OF DETROIT, MICHIGAN

Results of 'Before' and 'After' Study for Total and Targeted Crashes for Intersections Along Grand River Avenue Corridor

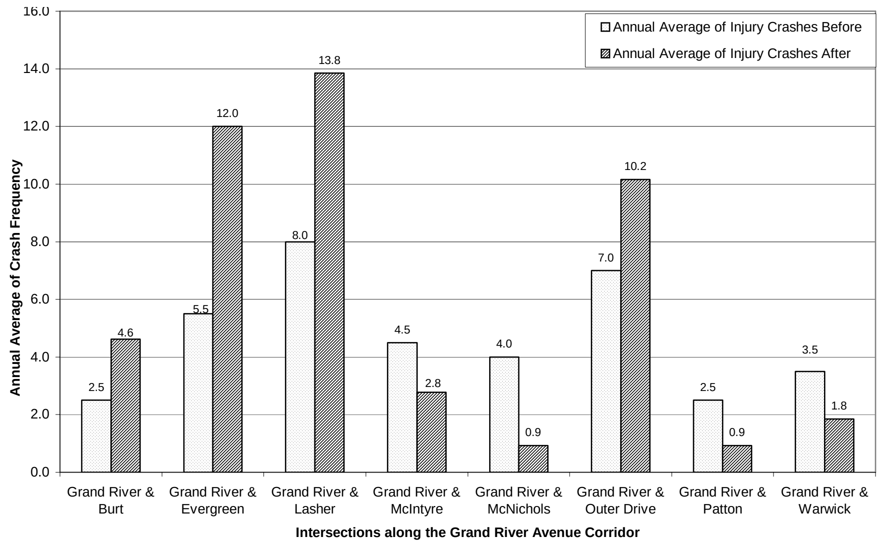
INTERSECTIONS ALONG GRAND RIVER AVENUE CORRIDOR	TOTAL CRASHES		INJURY CRASHES		ANGLE CRASHES		LEFT-TURN HEAD-ON CRASHES	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
Grand River Avenue and Burt Road	12.5	12.9	2.5	4.6	0.5	1.8	2.5	0.0
Grand River Avenue and Evergreen Road	27.0	20.3	5.5	12.0	4.0	3.7	1.5	1.8
Grand River Avenue and Lahser Road	31.5	37.8	8.0	13.8	2.5	3.7	2.5	2.8
Grand River Avenue and McIntyre Street	17.5	9.2	4.5	2.8	0.5	0.9	1.0	0.0
Grand River Avenue and McNichols Road	16.0	15.7	4.0	0.9	2.5	0.9	0.5	0.9
Grand River Avenue and Outer Drive	24.0	26.8	7.0	10.2	6.5	10.2	2.0	2.8
Grand River Avenue and Patton Street	7.5	4.6	2.5	0.9	2.0	0.9	0.5	0.0
Grand River Avenue and Warwick Street	8.5	9.2	3.5	1.8	1.0	0.0	0.5	0.9
Total	**144.5**	**136.5**	**37.5**	**47.0**	**19.5**	**22.1**	**11.0**	**9.2**

Grand River Avenue Corridor

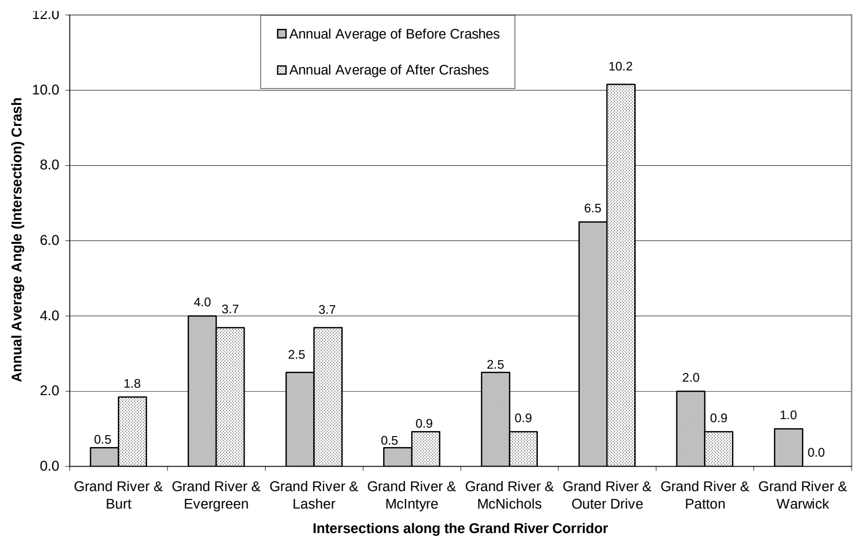
Before Data and After Data: UD-10 Forms

PREDOMINANCE CRASH TYPES	BEFORE AND AFTER STUDY				POISSON TEST OF SIGNIFICANCE @ alpha = 0.05
	'BEFORE' CRASHES	'AFTER' CRASHES	DIFFERENCE		
	Annual Average of Before Data	Annual Average of After Data	'Before'- 'After'	Reduction	
Rear End	45.5	47.1	-1.6	-	-
Angle (Intersection)	19.5	22.1	-2.6	-	-
Left-Turn Head-On	11.0	9.2	1.8	16%	No
Sideswipe	22.5	28.6	-6.1	-	-
Other	47.5	29.5	18.0	38%	Yes
TOTAL	**144.5**	**136.5**	9.4	6%	**Yes**
Injury	37.5	47.0	-9.6	-	-

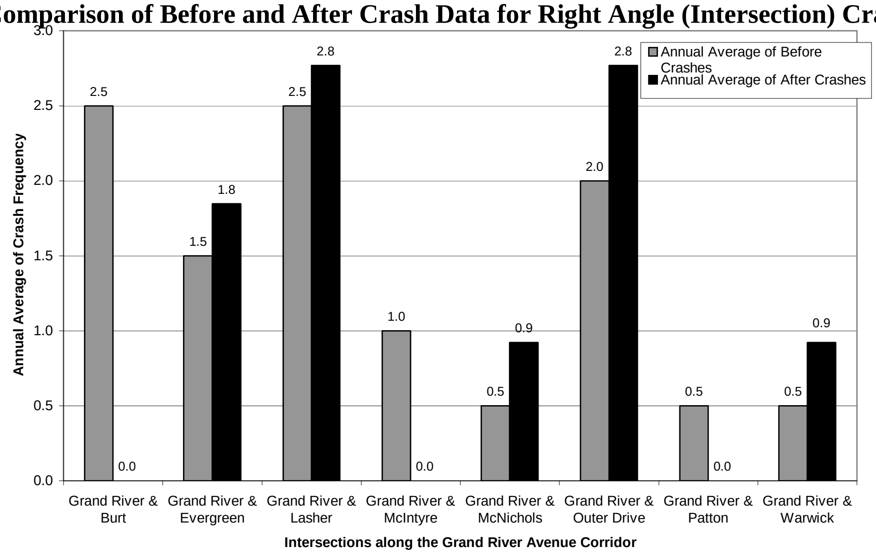
Comparison of Injury, Right Angle and Left-Turn Head-On Crashes for Before and After Period for Grand River Avenue Corridor



Comparison of Before and After Crash Data for Injury Crashes



Comparison of Before and After Crash Data for Right Angle (Intersection) Crashes



Comparison of Before and After Crash Data for Left-Turn Head-On Crashes

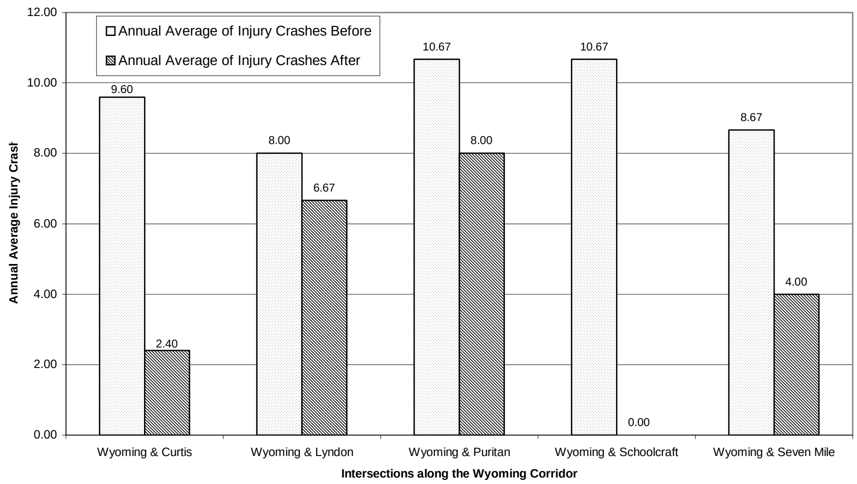
APPENDIX IV – SUMMARY OF THE 'BEFORE AND AFTER' CRASH ANALYSIS FOR THE WYOMING ROAD CORRIDOR INTERSECTIONS IN THE CITY OF DETROIT, MICHIGAN

Wyoming Road Corridor

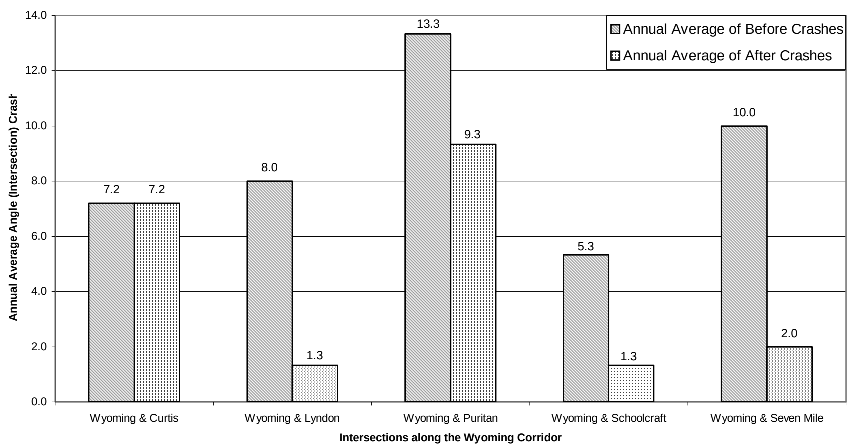
Before Data and After Data: UD-10 Forms

PREDOMINANCE CRASH TYPES	**BEFORE AND AFTER STUDY**				**POISSON TEST OF SIGNIFICANCE @ alpha = 0.05**
	'BEFORE' CRASHES	**'AFTER' CRASHES**	**DIFFERENCE**		
	Annual Average of Before Data	**Annual Average of After Data**	**'Before'- 'After'**	**Reduction**	
Rear End	54.5	33.7	20.8	38%	Yes
Angle (Intersection)	43.8	21.1	22.7	52%	Yes
Left-Turn Head-On	21.5	5.2	16.3	76%	Yes
Sideswipe	21.9	17.2	4.7	21%	No
Other	29.1	25.7	3.4	12%	No
TOTAL	**176.2**	**103.0**	**73.2**	41%	**Yes**
Injury	47.7	21.1	26.7	56%	Yes

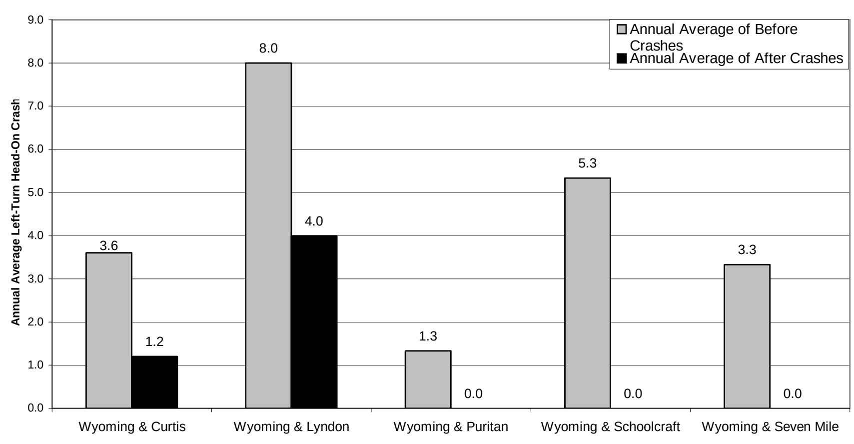
Comparison of Injury, Right Angle and Left-Turn Head-On Crashes for Before and After Period for Wyoming Street Corridor



Comparison of Before and After Crash Data for Injury Crashes



Comparison of Before and After Crash Data for Right Angle (Intersection) Crashes



Comparison of Before and After Crash Data for Left-Turn Head-On Crashes

Results of ‘Before’ and ‘After’ Study for Total and Targeted Crashes for Intersections Along Wyoming Road Corridor

INTERSECTIONS ALONG WYOMING ROAD CORRIDOR	TOTAL CRASHES		INJURY CRASHES		ANGLE CRASHES		LEFT-TURN HEAD-ON CRASHES	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
Wyoming Road and Curtis Road	22.8	14.4	9.6	2.4	7.2	7.2	3.6	1.2
Wyoming Road and Lyndon Road	54.7	20.0	8.0	6.7	8.0	1.3	8.0	4.0
Wyoming Road and Puritan Road	28.0	25.3	10.7	8.0	13.3	9.3	1.3	0.0
Wyoming Road and Schoolcraft Road	34.7	17.3	10.7	0.0	5.3	1.3	5.3	0.0
Wyoming Road and Seven Mile Road	36.0	26.0	8.7	4.0	10.0	2.0	3.3	0.0
Total	**176.2**	**103.0**	**47.7**	**21.1**	**43.8**	**21.1**	**21.5**	**5.2**

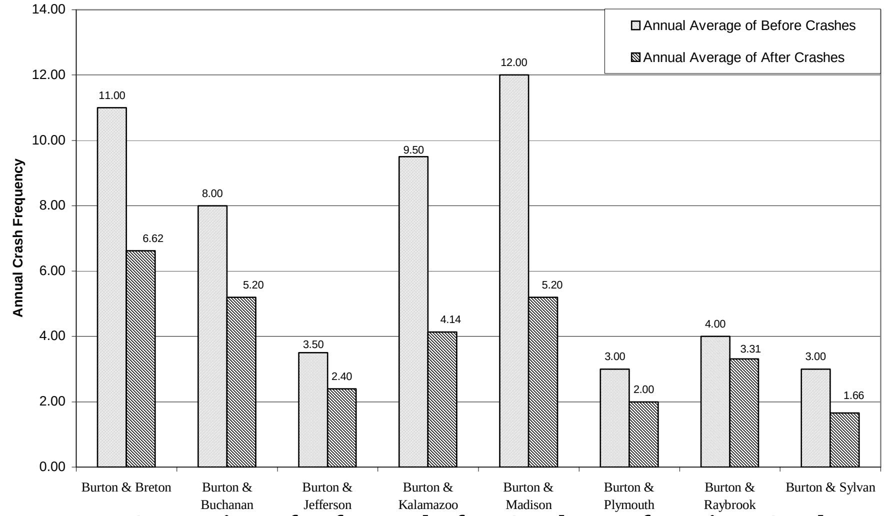
APPENDIX V – SUMMARY OF THE 'BEFORE AND AFTER' CRASH ANALYSIS FOR THE BURTON STREET CORRIDOR INTERSECTIONS IN THE CITY OF GRAND RAPIDS, MICHIGAN

Burton Street Corridor

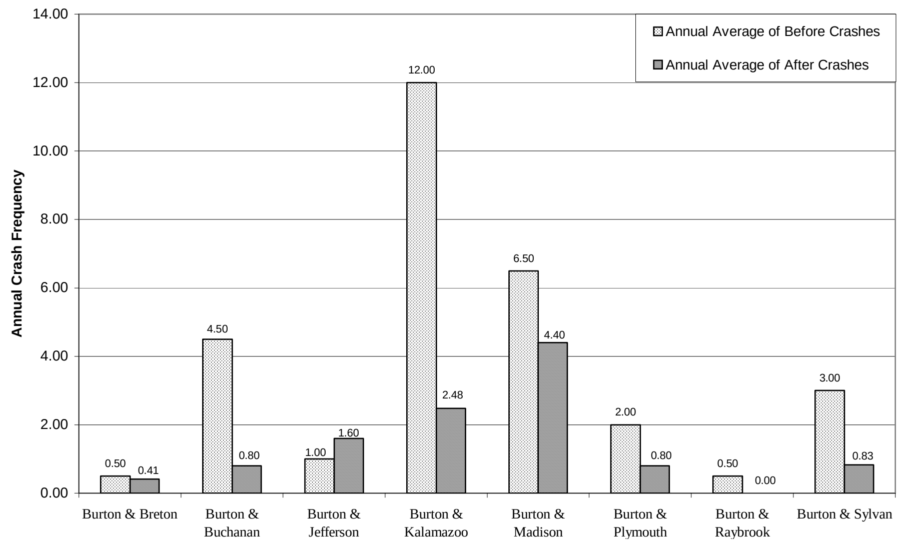
Before Data and After Data: UD-10 Forms

PREDOMINANCE CRASH TYPES	BEFORE AND AFTER STUDY				POISSON TEST OF SIGNIFICANCE @ alpha = 0.05
	‘BEFORE’ CRASHES	‘AFTER’ CRASHES	DIFFERENCE		
	12-Month Average of 2-Year Data	12-Month Average of After Data	‘Before’- ‘After’	Reduction	
Rear End	66.0	59.3	6.7	10%	No
Angle (Intersection)	30.0	11.3	18.7	62%	Yes
Left-Turn Head-On	42.5	17.8	24.7	58%	Yes
Sideswipe	25.0	22.4	2.6	10%	No
Other	35.5	21.6	13.9	39%	Yes
TOTAL	199.0	132.4	66.6	33%	**Yes**
Injury	54.0	30.5	23.5	44%	Yes

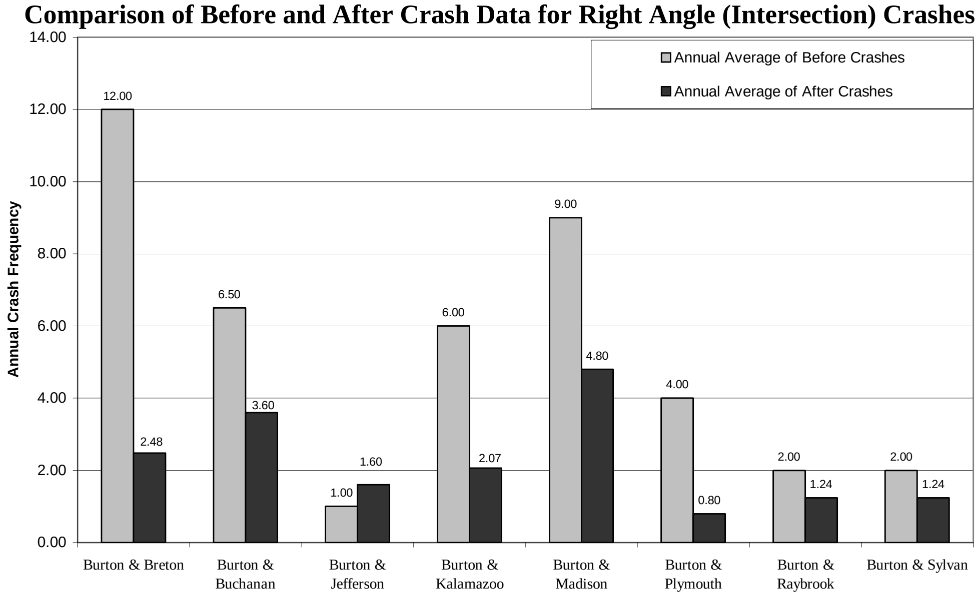
Comparison of Injury, Right Angle and Left-Turn Head-On Crashes for Before and After Period for Burton Street Corridor



Comparison of Before and After Crash Data for Injury Crashes



Comparison of Before and After Crash Data for Right Angle (Intersection) Crashes



Comparison of Before and After Crash Data for Left-Turn Head-On Crashes

Results of 'Before' and 'After' Study for Total and Targeted Crashes for Intersections Along Burton Street Corridor

INTERSECTIONS ALONG BURTON STREET CORRIDOR	TOTAL CRASHES		INJURY CRASHES		ANGLE CRASHES		LEFT-TURN HEAD-ON CRASHES	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
Burton Avenue and Breton Street	57.0	33.1	11.0	6.6	0.5	0.4	12.0	2.5
Burton Avenue and Buchanan Avenue	25.5	20.0	8.0	5.2	4.5	0.8	6.5	3.6
Burton Avenue and Jefferson Avenue	14.0	10.8	3.5	2.4	1.0	1.6	1.0	1.6
Burton Avenue and Kalamazoo Avenue	36.0	19.9	9.5	4.1	12.0	2.5	6.0	2.1
Burton Avenue and Madison Road	27.0	19.6	12.0	5.2	6.5	4.4	9.0	4.8
Burton Avenue and Plymouth Road	14.0	10.4	3.0	2.0	2.0	0.8	4.0	0.8
Burton Avenue and Raybrook Avenue	15.5	12.4	4.0	3.3	0.5	0.0	2.0	1.2
Burton Avenue and Sylvan Avenue	10.0	6.2	3.0	1.7	3.0	0.8	2.0	1.2
Total	**199.0**	**132.4**	**54.0**	**30.5**	**30.0**	**11.3**	**42.5**	**17.8**

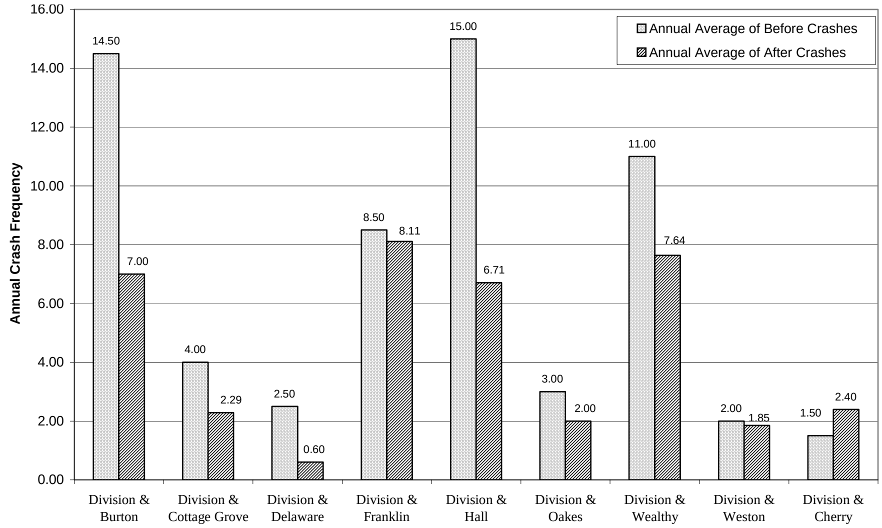
APPENDIX VI – SUMMARY OF THE ‘BEFORE AND AFTER’ CRASH ANALYSIS FOR THE DIVISION AVENUE CORRIDOR INTERSECTIONS IN THE CITY OF GRAND RAPIDS, MICHIGAN

Division Avenue Corridor

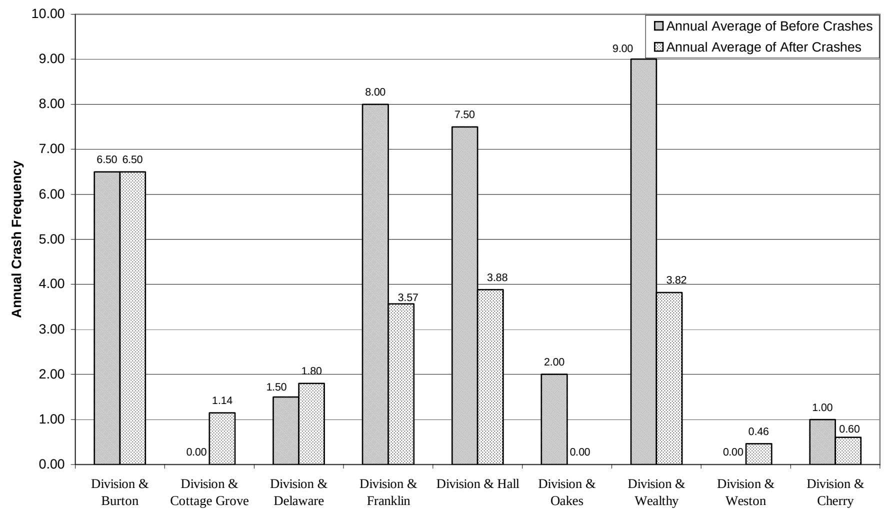
Before Data and After Data: UD-10 Forms

PREDOMINANCE CRASH TYPES	BEFORE AND AFTER STUDY				POISSON TEST OF SIGNIFICANCE @ alpha = 0.05
	'BEFORE' CRASHES	'AFTER' CRASHES	DIFFERENCE		
	Annual Average of 2-Year Data	Annual Average of After Data	'Before'-'After'	Reduction	
Rear End	56.0	67.3	-11.3	-20%	No
Angle (Intersection)	35.5	21.8	13.7	39%	Yes
Left-Turn Head-On	45.0	18.9	26.1	58%	Yes
Sideswipe	30.5	28.9	1.6	5%	No
Other	41.0	46.6	-5.6	-14%	No
TOTAL	**208.0**	**183.5**	**24.5**	**12%**	**No**
Injury	62.0	38.6	23.4	38%	Yes

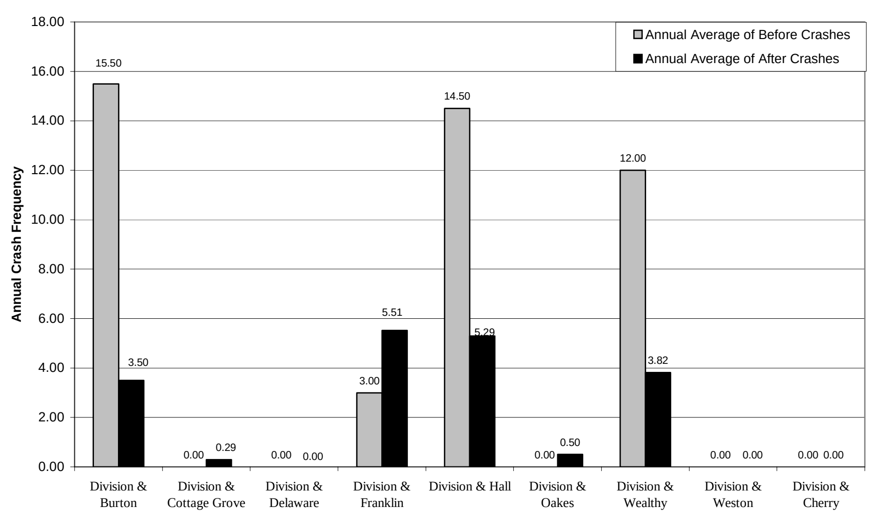
Comparison of Injury, Right Angle and Left-Turn Head-On Type of Crashes for the Before and After Period for Division Avenue Corridor



Comparison of Before and After Crash Data for Injury Crashes



Comparison of Before and After Crash Data for Right Angle (Intersection) Crashes



Comparison of Before and After Crash Data for Left-Turn Head-On Crashes

Results of 'Before' and 'After' Study for Total and Targeted Crashes for Intersections Along Division Avenue Corridor

INTERSECTIONS ALONG DIVISION AVENUE CORRIDOR	TOTAL CRASHES		INJURY CRASHES		ANGLE CRASHES		LEFT-TURN HEAD-ON CRASHES	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
Division Avenue and Cherry Street	7.0	9.6	1.5	2.4	1.0	0.6	0.0	0.0
Division Avenue and Weston Street	8.0	6.0	2.0	1.8	0.0	0.5	0.0	0.0
Division Avenue and Wealthy Street	40.5	32.2	11.0	7.6	9.0	3.8	12.0	3.8
Division Avenue and Oakes Street	10.0	5.5	3.0	2.0	2.0	0.0	0.0	0.5
Division Avenue and Hall Street	42.5	29.6	15.0	6.7	7.5	3.9	14.5	5.3
Division Avenue and Franklin Street	27.0	29.8	8.5	8.1	8.0	3.6	3.0	5.5
Division Avenue and Delaware Street	7.0	3.6	2.5	0.6	1.5	1.8	0.0	0.0
Division Avenue and Cottage Grove	8.0	13.7	4.0	2.3	0.0	1.1	0.0	0.3
Division Avenue and Burton Street	58.0	53.5	14.5	7.0	6.5	6.5	15.5	3.5
Total	**208.0**	**183.5**	**62.0**	**38.5**	**35.5**	**21.8**	**45.0**	**18.9**

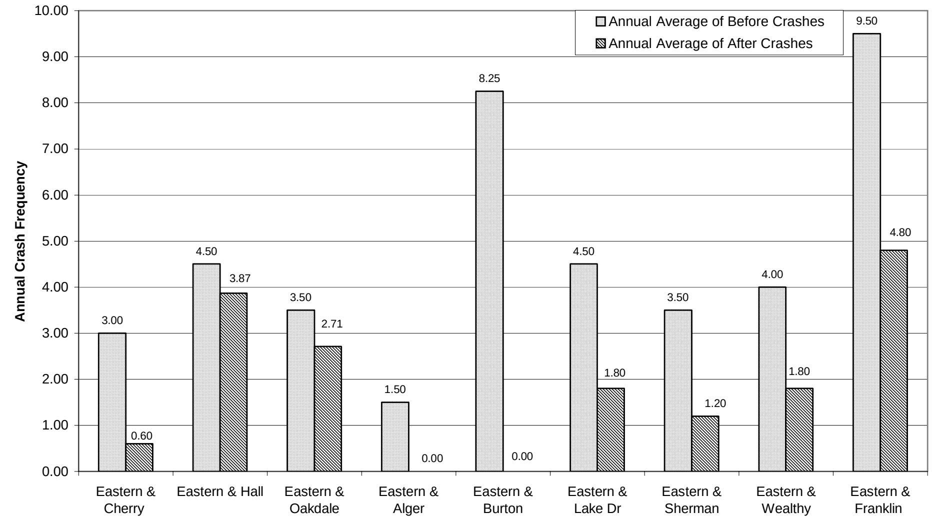
APPENDIX VII – SUMMARY OF THE 'BEFORE AND AFTER' CRASH ANALYSIS FOR THE EASTERN AVENUE CORRIDOR INTERSECTIONS IN THE CITY OF GRAND RAPIDS, MICHIGAN

Eastern Avenue Corridor

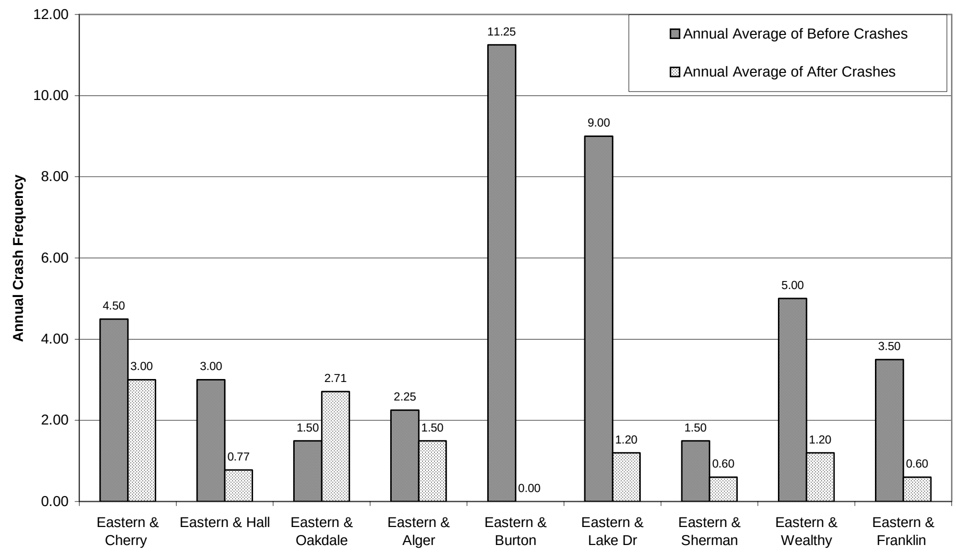
Before Data and After Data: UD-10 Forms

PREDOMINANCE CRASH TYPES	BEFORE AND AFTER STUDY				POISSON TEST OF SIGNIFICANCE @ alpha = 0.05
	'BEFORE' CRASHES	'AFTER' CRASHES	DIFFERENCE		
	12-Month Average of 2-Year Data	12-Month Average of After Data	'Before'-'After'	Reduction	
Rear End	43.5	32.8	10.7	25%	No
Angle (Intersection)	41.5	11.6	29.9	72%	Yes
Left-Turn Head-On	24.6	11.3	13.3	54%	Yes
Sideswipe	25.0	15.1	9.9	40%	Yes
Other	16.9	22.6	-5.7	-34% (Increase)	No
TOTAL	**151.4**	**101.0**	**50.4**	**33%**	**Yes**
Injury	42.3	16.8	25.5	60%	Yes

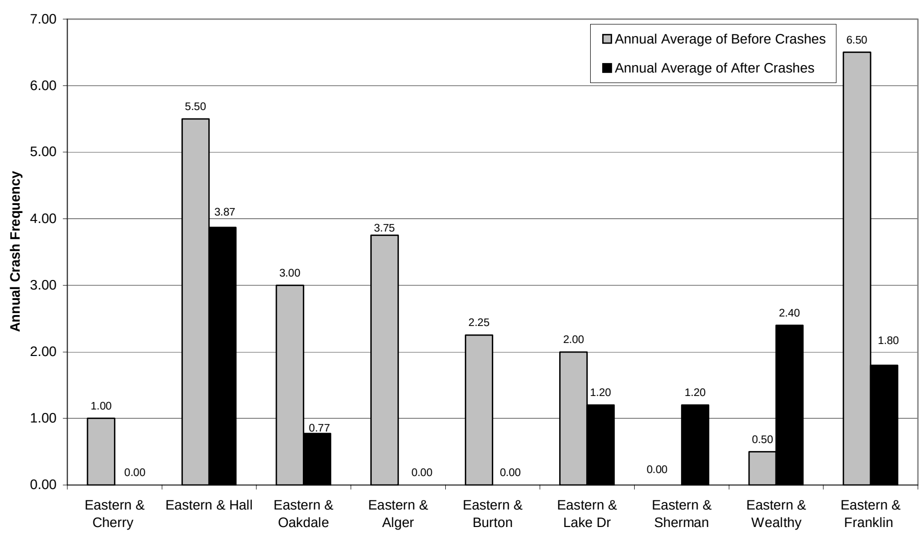
Comparison of Injury, Right Angle, Left-Turn Head-On Crashes for Before and After Period for Eastern Avenue Corridor



Comparison of Before and After Crash Data for Injury Crashes for the Intersections



Comparison of Before and After Crash Data for Right Angle (Intersection) Crashes



Comparison of Before and After Crash Data for Left-Turn Head-On Crashes

Results of 'Before' and 'After' Study for Total and Targeted Crashes for Intersections Along Eastern Avenue Corridor

INTERSECTIONS ALONG EASTERN AVENUE CORRIDOR	TOTAL CRASHES		INJURY CRASHES		ANGLE CRASHES		LEFT-TURN HEAD-ON CRASHES	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
Eastern Avenue and Cherry Street	12.5	4.2	3.0	0.6	4.5	3.0	1.0	0.0
Eastern Avenue and Hall Street	11.0	12.8	4.5	3.9	3.0	0.8	5.5	3.9
Eastern Avenue and Oakdale Street	10.5	11.6	3.5	2.7	1.5	2.7	3.0	0.8
Eastern Avenue and Alger Street	14.2	12.7	1.5	0.0	2.2	1.5	3.8	0.0
Eastern Avenue and Burton Street	38.2	16.5	8.3	0.0	11.3	0.0	2.3	0.0
Eastern Avenue and Lake Drive	14.5	4.8	4.5	1.8	9.0	1.2	2.0	1.2
Eastern Avenue and Sherman Street	13.0	6.6	3.5	1.2	1.5	0.6	0.0	1.2
Eastern Avenue and Wealthy Street	11.5	12.0	4.0	1.8	5.0	1.2	0.5	2.4
Eastern Avenue and Franklin Street	26.0	19.8	9.5	4.8	3.5	0.6	6.5	1.8
Total	**151.4**	**101.0**	**42.3**	**16.8**	**41.5**	**11.6**	**24.6**	**11.3**

APPENDIX VIII – INDIVIDUAL INTERSECTION SUMMARY FOR ISOLATED INTERSECTIONS IN THE CITIES OF DETROIT AND GRAND RAPIDS, MICHIGAN

Results of 'Before' and 'After' Study for Total and Targeted Crashes for the Isolated Intersections in the City of Detroit, Michigan

ISOLATED INTERSECTIONS IN THE CITY OF DETROIT	TOTAL CRASHES (Average per 12 month)			INJURY CRASHES			ANGLE CRASHES			LEFT-TURN HEAD-ON CRASHES		
	BEFORE	AFTER	% REDUC-TION	BEFORE	AFTER	% REDUC-TION	BEFORE	AFTER	% REDUC-TION	BEFORE	AFTER	% REDUC-TION
Seven Mile Road and John R Road	51.7	25.4	51%*	16.7	6.0	64%*	12.0	4.2	65%*	15.0	2.8	81%*
Seven Mile Road and Ryan Road	68.0	31.4	51%*	18.7	5.3	71%*	18.3	3.8	77%*	20.0	2.6	85%*
Hubbell Road and Puritan Road	35.0	14.7	58%*	13.3	4.3	68%*	20.3	3.1	85%*	4.0	1.0	75%**
Schoolcraft Road and Evergreen Avenue	37.9	25.0	34%*	14.7	8.8	40%*	5.3	1.8	66%*	7.3	5.0	32%*
Leonard Street and College Avenue	25.0	7.8	69%*	5.5	2.8	49%*	4.0	1.3	68%**	7.5	1.3	83%*
Cadieux and I-94 Service Drives	28.0	15.7	44%*	6.0	5.5	8%	11.0	1.8	84%*	0.0	0.0	0%
Dexter Road and Davison Avenue	40.0	45.0	-12.5%	11.0	13.5	-23%	4.0	3.0	25%**	6.0	6.0	0%
Harper Avenue and Cadieux Avenue	35.0	25.8	26%*	5.0	3.7	26%*	2.0	0.9	55%**	1.0	0.0	100%**
Harper Avenue and Dickerson Road	34.0	30.5	10%*	10.0	7.4	26%*	8.0	3.7	54%*	7.0	8.3	-19%
McNichols Road and Schaefer Highway	40.0	40.0	0%	14.0	8.0	43%*	2.0	2.0	0%	8.0	2.0	75%*
Schaefer Highway and Seven Mile Road	37.5	18.0	52%*	10.5	4.5	57%*	6.0	0.0	100%*	3.0	1.5	50%**

* Denotes Poisson Test of Significance at 95 percent Level of Confidence
** Denotes too low frequency of before crashes to test for Poisson Significance

APPENDIX IX – SUMMARY OF ‘BEFORE AND AFTER’ VOLUME DATA AT THE SELECTED TEST AND CONTROL INTERSECTIONS IN THE CITY OF GRAND RAPIDS AND CITY OF DETROIT, MICHIGAN

SERIAL NO.	TYPE	INTERSECTIONS IN GRAND RAPIDS	ENTERING TRAFFIC VOLUME	
			‘BEFORE’ ADT VPD	‘AFTER’ ADT VPD
1	Test	Leonard Street and College Avenue	30,386	39,272
	Control	Leonard Street and Lafayette Avenue	22,652	28,000
2	Test	Burton Street and Kalamazoo Avenue	37,000	36,518
	Control	Michigan Street and College Avenue	38,143	35,950
3	Test	Burton Street and Breton Avenue	60,857	64,814
	Control	Michigan Street and Fuller Avenue	48,335	51,478
4	Test	Eastern Avenue and Franklin Street	27,572	26,830
	Control	Fulton Street and Lafayette Street	36,384	34,358

VPD = Vehicles per Day

SERIAL NO.	TYPE	INTERSECTIONS IN CITY OF DETROIT	ENTERING TRAFFIC VOLUME	
			‘BEFORE’ ADT VPD	‘AFTER’ ADT VPD
1	Test	Seven Mile Road and Ryan Road	25,529	28,249
	Control	Seven Mile Road and Dequindre Road	22,059	24,786
2	Test	Hubbell Road and Puritan Road	23,143	22,529
	Control	Meyers Road and Puritan Road	30,069	30,714
3	Test	Wyoming Road and Lyndon Road	35,372	36,000
	Control	Hubbell Road and Joy Road	27,664	28,142
4	Test	Schaefer Highway and Seven Mile Road	48,428	41,164
	Control	Evergreen Road and Seven Mile Road	47,971	49,170

VPD = Vehicles per Day

APPENDIX X – DETAILS OF THE REGRESSION EQUATION DEVELOPED FOR USE IN THE EMPIRICAL BAYES ANALYSIS

Regression

Descriptive Statistics

	Mean	Std. Deviation	N
LN Annual Crash Frequency	*********	************	21
LN Intersection ADT	*********	************	21
LN Prop of Minor Street	*********	************	21

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.819[a]	.670	.633	***********	.670	18.272	2	18	.000

a. Predictors: (Constant), LN Prop of Minor Street, LN Intersection ADT

b. Dependent Variable: LN Annual Crash Frequency

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.531	2	1.766	18.272	.000[a]
	Residual	1.739	18	9.664E-02		
	Total	5.271	20			

a. Predictors: (Constant), LN Prop of Minor Street, LN Intersection ADT

b. Dependent Variable: LN Annual Crash Frequency

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-10.093	2.205		-4.578	.000
	LN Intersection ADT	1.222	.203	.837	6.010	.000
	LN Prop of Minor Street	-.461	.228	-.282	-2.023	.058

a. Dependent Variable: LN Annual Crash Frequency

Regression Analysis: City of Detroit

Descriptive Statistics

	Mean	Std. Deviation	N
LN Annual Average Total Crashes	3.365	.6001	55
LN ADT	********	***********	55
LN Prop Minor St	********	***********	55

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.811[a]	.659	.645	.3573	.659	50.141	2	52	.000

a. Predictors: (Constant), LN Prop Minor St, LN ADT

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12.806	2	6.403	50.141	.000[a]
	Residual	6.640	52	.128		
	Total	19.446	54			

a. Predictors: (Constant), LN Prop Minor St, LN ADT

b. Dependent Variable: LN Annual Average Total Crashes

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-5.743	1.471		-3.904	.000
	LN ADT	.921	.139	.565	6.626	.000
	LN Prop Minor St	.361	.071	.431	5.051	.000

a. Dependent Variable: LN Annual Average Total Crashes

APPENDIX XI – INTERSECTIONS INCLUDED IN EACH OF THE GROUPS, AS WELL AS THEIR 'BEFORE' AND 'AFTER' CRASH FREQUENCIES FOR EACH OF THE TESTED COUNTERMEASURES

Countermeasure: 12-inch Signal Lenses and All-Red Intervals (40 Sites)

Angle Crashes

Corridor/Intersection	**Before Period** (Annual Average Crash Frequency) Crashes per Year B	**After Period** (Annual Average Crash Frequency) Crashes per Year A	**% Reduction (=B-A/B)**	**POISSON TEST OF SIGNIFICANCE @ alpha = 0.05**
Woodward Corridor (30 intersections)	100.0	24.4	76%	Yes
Division Ave & Cottage Grove	0.0	1.1	-	-
Burton Street & Sylvan	3.0	0.8	73%	Too Low Frequency
Division Ave & Delaware	1.5	1.8	-20%	Too Low Frequency
Burton Street & Jefferson	1.0	1.6	-60%	Too Low Frequency
Harper & Dickerson	8.0	3.7	54%	Yes
Eastern Ave & Burton Street	11.3	0.0	100%	Yes
Burton Street & Breton	0.5	0.4	20%	Too Low Frequency
Cadieux & Ford Frwy Service Dr	11.0	1.8	83%	Yes
Dexter & Davison	4.0	3.0	25%	Too Low Frequency
Burton & Raybrook	0.5	0.0	100%	Too Low Frequency
Total :	**140.8**	**38.6**	**72%**	**Yes**

Total Crashes

Corridor/Intersection	**Before Period** (Annual Average Crash Frequency) Crashes per Year B	**After Period** (Annual Average Crash Frequency) Crashes per Year A	**% Reduction (=B-A/B)**	**POISSON TEST OF SIGNIFICANCE @ alpha = 0.05**
Woodward Corridor (30 intersections)	388.5	272.5	30%	Yes
Division Ave & Cottage Grove	8.0	13.7	-71%	-
Burton Street & Sylvan	10.0	6.2	38%	No
Division Ave & Delaware	7.0	3.6	49%	No
Burton Street & Jefferson	14.0	10.8	23%	No
Harper & Dickerson	34.0	30.5	10%	No
Eastern Ave & Burton Street	38.3	16.5	57%	Yes
Burton Street & Breton	57.0	33.1	42%	Yes
Cadieux & Ford Frwy Service Dr	28.0	15.7	44%	Yes
Dexter & Davison	40.0	45.0	-13%	-
Burton & Raybrook	15.5	12.4	20%	No
Total :	**640.3**	**460.0**	**28%**	**Yes**

Injury Crashes

Corridor/Intersection	**Before Period** (Annual Average Crash Frequency) Crashes per Year B	**After Period** (Annual Average Crash Frequency) Crashes per Year A	**% Reduction (=B-A/B)**	**POISSON TEST OF SIGNIFICANCE @ alpha = 0.05**
Woodward Corridor (30 intersections)	109.5	64.6	41%	Yes
Division Ave & Cottage Grove	4.0	2.3	43%	Too Low Frequency
Burton Street & Sylvan	3.0	1.7	43%	Too Low Frequency
Division Ave & Delaware	2.5	0.6	76%	Too Low Frequency
Burton Street & Jefferson	3.5	2.4	31%	Too Low Frequency
Harper & Dickerson	10.0	7.4	26%	No
Eastern Ave & Burton Street	8.3	0.0	100%	Yes
Burton Street & Breton	11.0	6.6	40%	No
Cadieux & Ford Frwy Service Dr	6.0	5.5	8%	No
Dexter & Davison	11.0	13.5	-23%	-
Burton & Raybrook	4.0	3.3	17%	Too Low Frequency
Total :	**172.8**	**107.9**	**38%**	**Yes**

Countermeasure: Exclusive Left-Turn Lanes Only (8 Sites)				
Left-Turn Head-On Crashes				
Corridor/Intersection	**Before Period** (Annual Average Crash Frequency) Crashes per year B	**After Period** (Annual Average Crash Frequency) Crashes per year A	**% Reduction (=B-A/B)**	**POISSON TEST OF SIGNIFICANCE @ alpha = 0.05**
Hubbell & Puritan	4.0	1.0	75%	Too Low Frequency
Schoolcraft & Evergreen	7.3	5.0	32%	No
Wyoming Road & Curtis	3.6	1.2	67%	Too Low Frequency
Eastern Ave & Cherry	1.0	0.0	100%	Too Low Frequency
Eastern Ave & Hall	5.5	3.9	29%	No
Eastern Ave & Oakdale	3.0	0.8	73%	Too Low Frequency
Eastern Ave & Sherman	0.0	1.2	-	Too Low Frequency
Leonard & College	7.5	1.3	83%	Yes
Total :	**31.9**	**14.4**	**55%**	**Yes**

Total Crashes				
Corridor/Intersection	**Before Period** (Annual Average Crash Frequency) Crashes per year B	**After Period** (Annual Average Crash Frequency) Crashes per year A	**% Reduction (=B-A/B)**	**POISSON TEST OF SIGNIFICANCE @ alpha = 0.05**
Hubbell & Puritan	35.0	14.7	58%	Yes
Schoolcraft & Evergreen	37.0	25.0	32%	Yes
Wyoming Road & Curtis	22.8	14.4	37%	Yes
Eastern Ave & Cherry	12.5	4.2	66%	Yes
Eastern Ave & Hall	11.0	12.8	-16%	-
Eastern Ave & Oakdale	10.5	11.6	-11%	-
Eastern Ave & Sherman	13.0	6.6	49%	Yes
Leonard & College	25.0	7.7	69%	Yes
Total :	**166.8**	**96.9**	**42%**	**Yes**

Injury Crashes				
Corridor/Intersection	**Before Period** (Annual Average Crash Frequency) Crashes per year B	**After Period** (Annual Average Crash Frequency) Crashes per year A	**% Reduction (=B-A/B)**	**POISSON TEST OF SIGNIFICANCE @ alpha = 0.05**
Hubbell & Puritan	13.3	4.3	67%	Yes
Schoolcraft & Evergreen	14.7	8.8	40%	No
Wyoming Road & Curtis	9.6	2.4	75%	Yes
Eastern Ave & Cherry	3.0	0.6	80%	Too Low Frequency
Eastern Ave & Hall	4.5	3.9	14%	No
Eastern Ave & Oakdale	3.5	2.7	23%	Too Low Frequency
Eastern Ave & Sherman	3.5	1.2	66%	Too Low Frequency
Leonard & College	5.5	2.8	49%	No
Total :	**57.6**	**26.7**	**54%**	**Yes**

Countermeasure: Exclusive Left-Turn Lanes and Left-Turn Phase (11 Sites)

Left-Turn Head-On Crashes

Corridor/Intersection	**Before Period** (Annual Average Crash Frequency) Crashes per year B	**After Period** (Annual Average Crash Frequency) Crashes per year A	% Reduction (=B-A/B)	POISSON TEST OF SIGNIFICANCE @ alpha = 0.05
Wyoming Ave & Puritan	1.3	0.0	100%	Too Low Frequency
Wyoming Ave & Lyndon	8.0	4.0	50%	No
Wyoming Ave & Schoolcraft	5.3	0.0	100%	Yes
Eastern Ave & Wealthy	0.5	2.4	-380%	-
Eastern Ave & Franklin	6.5	1.8	72%	Yes
Division Ave & Burton Street	15.5	3.5	77%	Yes
Division Ave & Franklin	3.0	5.5	-83%	-
Division Ave & Hall	14.5	5.3	63%	Yes
Seven Mile & Ryan	20.0	2.6	87%	Yes
Seven Mile & John R	15.0	2.8	81%	Yes
Eastern & Lake	2.0	1.2	40%	Too Low Frequency
Total :	**91.6**	**29.1**	**68%**	**Yes**

Total Crashes

Corridor/Intersection	**Before Period** (Annual Average Crash Frequency) Crashes per year B	**After Period** (Annual Average Crash Frequency) Crashes per year A	% Reduction (=B-A/B)	POISSON TEST OF SIGNIFICANCE @ alpha = 0.05
Wyoming Ave & Puritan	28.0	25.3	10%	No
Wyoming Ave & Lyndon	54.7	20.0	63%	Yes
Wyoming Ave & Schoolcraft	34.7	17.3	50%	Yes
Eastern Ave & Wealthy	11.5	12.0	-4%	-
Eastern Ave & Franklin	26.0	19.8	24%	No
Division Ave & Burton Street	58.0	53.5	8%	No
Division Ave & Franklin	27.0	29.8	-10%	-
Division Ave & Hall	42.5	29.6	30%	Yes
Seven Mile & Ryan	68.0	31.4	54%	Yes
Seven Mile & John R	51.7	25.4	51%	Yes
Eastern & Lake	14.5	4.8	67%	Yes
Total :	**416.5**	**268.9**	**35%**	**Yes**

Injury Crashes

Corridor/Intersection	**Before Period** (Annual Average Crash Frequency) Crashes per year B	**After Period** (Annual Average Crash Frequency) Crashes per year A	% Reduction (=B-A/B)	POISSON TEST OF SIGNIFICANCE @ alpha = 0.05
Wyoming Ave & Puritan	10.7	8.0	25%	No
Wyoming Ave & Lyndon	8.0	6.7	16%	No
Wyoming Ave & Schoolcraft	10.7	0.0	100%	Yes
Eastern Ave & Wealthy	4.0	1.8	55%	Too Low Frequency
Eastern Ave & Franklin	9.5	4.8	49%	Yes
Division Ave & Burton Street	14.5	7.0	52%	Yes
Division Ave & Franklin	8.5	8.1	5%	No
Division Ave & Hall	15.0	6.7	55%	Yes
Seven Mile & Ryan	18.7	5.3	72%	Yes
Seven Mile & John R	16.7	6.0	64%	Yes
Eastern & Lake	4.5	1.8	60%	No
Total :	**120.7**	**56.2**	**53%**	**Yes**

Countermeasure: Exclusive Left-Turn Phase Only (10 Sites)

Left-Turn Head-On Crashes

Corridor/Intersection	**Before Period** (Annual Average Crash Frequency) Crashes per year B	**After Period** (Annual Average Crash Frequency) Crashes per year A	% Reduction (=B-A/B)	POISSON TEST OF SIGNIFICANCE @ alpha = 0.05
Seven Mile Rd & Schaefer	3.0	1.5	50%	Too Low Frequency
Schaefer & McNichols	8.0	2.0	75%	Yes
Wyoming Rd & Seven Mile Rd	3.3	0.0	100%	Too Low Frequency
Harper & Cadieux	1.0	0.0	100%	Too Low Frequency
Division Ave & Wealthy	12.0	3.8	68%	Yes
Burton Street & Buchanan	6.5	3.6	45%	No
Burton Street & Kalamazoo	6.0	2.1	65%	Yes
Burton Street & Madison	9.0	4.8	47%	No
Burton Street & Plymouth	4.0	0.8	80%	Too Low Frequency
Eastern & Alger	3.8	0.0	100%	Too Low Frequency
Total:	**56.6**	**18.6**	**67%**	**Yes**

Total Crashes

Corridor/Intersection	**Before Period** (Annual Average Crash Frequency) Crashes per year B	**After Period** (Annual Average Crash Frequency) Crashes per year A	% Reduction (=B-A/B)	POISSON TEST OF SIGNIFICANCE @ alpha = 0.05
Seven Mile Rd & Schaefer	37.5	18.0	52%	Yes
Schaefer & McNichols	40.0	40.0	0%	No
Wyoming Rd & Seven Mile Rd	36.0	26.0	28%	Yes
Harper & Cadieux	35.0	25.8	26%	No
Division Ave & Wealthy	40.5	32.2	20%	No
Burton Street & Buchanan	25.5	20.0	22%	No
Burton Street & Kalamazoo	36.0	19.9	45%	Yes
Burton Street & Madison	27.0	19.6	27%	No
Burton Street & Plymouth	14.0	10.4	26%	No
Eastern & Alger	14.3	4.50	68%	Yes
Total :	**305.8**	**216.4**	**29%**	**Yes**

Injury Crashes

Corridor/Intersection	**Before Period** (Annual Average Crash Frequency) Crashes per year B	**After Period** (Annual Average Crash Frequency) Crashes per year A	% Reduction (=B-A/B)	POISSON TEST OF SIGNIFICANCE @ alpha = 0.05
Seven Mile Rd & Schaefer	10.5	4.5	57%	Yes
Schaefer & McNichols	14.0	8.0	43%	Yes
Wyoming Rd & Seven Mile Rd	8.7	4.0	54%	Yes
Harper & Cadieux	5.0	3.7	26%	No
Division Ave & Wealthy	11.0	7.6	31%	No
Burton Street & Buchanan	8.0	5.2	35%	No
Burton Street & Kalamazoo	9.5	4.1	57%	Yes
Burton Street & Madison	12.0	5.2	57%	Yes
Burton Street & Plymouth	3.0	2.0	33%	Too Low Frequency
Eastern & Alger	1.5	0.0	100%	Too Low Frequency
Total :	**83.2**	**44.3**	**47%**	**Yes**