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Effectiveness of the all-red clearance interval on intersection crashes

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Effectiveness of the all-red clearance interval on intersection crashes

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Signatures have been redacted for privacy

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Abstract

Crashes at signalized intersections account for approximately 20% of all crashes both nationally and within the State of Minnesota. Several research efforts have suggested that the use of all-red clearance interval at signalized intersections may reduce intersection crashes, particularly those related to signal violations. However, other research has shown that an all-red interval does not result in a reduction in crash rate. This research also evaluated the reduction in crashes due to use of an all-red interval at intersections within the City of Minneapolis. A cross-section analysis using generalized linear mixed models with a Poisson error distribution and log link function and mixed linear models with transformed data were used to compare Minneapolis sites with and without the all-red clearance interval. Results of the analysis agree with the previous studies that indicate no effect. A before and after analysis was also conducted to evaluate both short and long term effects of the all-red interval. The before and after study did demonstrate a short-term reduction in crash rate lasting approximately one year after implementation of an all-red interval. The research also evaluated user costs in the form of increased delay due to reduction in capacity that would result from implementation of the all-red interval at the remaining Minneapolis intersections that currently do not use the interval. Although a short-term effect was noted, the temporary safety benefits may not outweigh the long-term reductions in capacity and should be considered before implementation. Additionally, although no statistically significant long-term benefit was demonstrated, research results do not provide guidance on elimination of the all-red clearance intervals at intersections where it is currently in use.

Chapter 1: Introduction

1.1. Background

Each year there are more than 1.8 Million intersection crashes in the United States. It is estimated that in 2001, 218,000 crashes, 181,000 injuries, and 880 fatalities nationally were associated with signal violations. The economic loss associated with red light running crashes at intersections is estimated at $14 billion per year and is increasing (FHWA ITE, 2003). All-red clearance intervals in which all movements receive a red indication were implemented to reduce crashes by providing additional time for vehicles to clear the intersection. Without an all-red interval, the yellow interval is followed immediately by a green interval for the opposing movements. This allows conflicting movements to start directly after the yellow interval. Currently, it is almost standard practice in the United States to incorporate the all-red clearance interval. Although commonly used, consensus on the effectiveness of the all-red interval has not been reached. A number of research efforts have suggested that the use of all-red phases at signalized intersections reduces intersection crashes, particularly those related to signal violations and those involving pedestrians and bicyclists. However, other research has shown that an all-red interval does not result in a reduction in crash rates.

Since no agreement exists on the effectiveness of an all-red clearance interval as a safety measure, the Minnesota Department of Transportation (DOT) commissioned this research to evaluate the benefits and costs of implementing the all-red clearance interval to determine whether to universally adopt the all-red interval. This research study assessed the short and long term safety impacts of the all-red clearance interval in the City of

Minneapolis, Minnesota through the use of a cross-section analysis, before and after analysis, and linear mixed models comparing Minneapolis sites with and without the all-red clearance interval.

1.2. Need for Research

Red light running is the leading cause of urban crashes (FHWA, 2003). Some literature on this topic has acknowledged that the use of the all-red clearance interval at signalized intersections may reduce intersection crashes. Several short-term (up to one year before and after implementation of all-red clearance interval) studies show that the all-red clearance interval is particularly beneficial in reducing intersection crashes related to signal violations. On the other hand, long-term (more than two years before and after implementation of the all-red clearance interval) research findings do not concur that these benefits are sustained in the long run. Seven studies show that the all-red clearance interval is effective in reducing intersection crashes, three show mixed results, and one found it to be ineffective in reducing intersection crashes.

In this study, three distinct types of analysis sites were considered: intersections historically (more than 4 years) operating with an all-red phase, intersections historically operating without an all-red phase, and intersections where all-red clearance intervals were recently implemented. First, in a cross-section study intersections historically operating with an all-red clearance interval are compared to intersections operating without an all-red clearance interval. A before and after analysis is used to compare intersections where an all-red clearance interval was added with a control group of intersections operating without the all-red clearance interval. Finally, a statistical analysis is performed using the cross-section study intersections. This analysis includes a generalized linear mixed model and a linear mixed model with different covariance structures to assess intersections with and without the all-red clearance interval.

1.2.1 Research Objectives and Scope of Work

The objective of this research was to determine whether there was a statistically significant difference in crash rates between intersections operating with and without an all-red clearance interval. A cross-section analysis, generalized linear mixed models, and linear mixed models compare Minneapolis intersections were used to determine the effects of implementing the all-red clearance interval. Short term and long-term impacts of the all-red clearance interval are investigated in the before and after analysis.

To accomplish the stated objectives, the scope of research included the following activities:

- A review of literature regarding the effectiveness of the all-red clearance interval and recommended all-red clearance interval timing practices.
- A review of Midwest signal phasing practices at the state and local level.
- Collection and identification of pertinent information regarding signalized intersections within the City of Minneapolis, Minnesota.
- Comparison of intersections with and without an all-red clearance interval using a cross-section analysis.
- A before and after analysis compared crash data for a group of intersections 5 years before and 6 years after the implementation of the all-red clearance interval.

- Generalized linear mixed models and linear mixed models with different covariance structures assess the impact of the all-red clearance interval at cross-study intersections.

1.2.2 Summary of Research Methodology

Minneapolis intersection plans were studied to limit the analysis to only intersections of two-way roads with four approaches were analyzed. Skewed, offset, or intersections with horizontal curves on approaches were not used. An intersection database was created for the analysis, and includes the following attributes: intersection number (defined by the City of Minneapolis), intersection name, treatment (all-red, no all-red), date of addition of the all-red clearance interval, accuracy of the all-red clearance interval addition date was noted because the all-red clearance interval addition date was not available at all intersections, speed, signal mount (overhead or pedestal), presence of street lighting at the intersection, Daily Entering Vehicles (DEV), all intersection crashes per year, and relevant intersection crashes per year (head on, rear end, right angle, left turn, right turn, and side swipe).

Once the database was completed, implications of the all-red clearance interval at intersections in Minneapolis were investigated using three different methods: a cross-section analysis, a before and after analysis, and linear mixed models. The purpose of the cross-section analysis is to determine if there is a difference in the number of crashes and crash rates at intersections operating with and without the all-red clearance interval. The before and after analysis investigates the short and long term impacts of the implementation of the all-red clearance interval compared to a control group of intersections without the all-red clearance interval. Finally, generalized linear mixed models and linear mixed models statistically investigate intersection safety based on intersection characteristics and the presence of the all-red clearance interval.

1.3 Benefits

This study utilizes statistical tests to determine if all-red clearance interval improves safety at signalized intersections. Traffic engineers may use these results to assess or justify the applicability of an all-red clearance interval, based on the expected safety performance at intersections. If the all-red clearance interval positively impacts intersection safety, a resultant decrease in crashes and corresponding losses may be quantified. If the all-red clearance interval does not appear to increase intersection safety, a program for the systematic inclusion of an all-red phase at all signalized locations may need to be reviewed. The time saved by not including an all-red clearance interval at intersections could increase the level of service and capacity at intersections. Figure 1.1 conceptually shows what happens to intersection delay as volume to capacity ratios increase. During off-peak hours when intersections are experiencing low volume to capacity ratios, the addition of the all-red clearance interval will not affect delay at intersections. During peak hours when the volume to capacity ratio is high, the presence of the all-red clearance interval increases intersection delay.

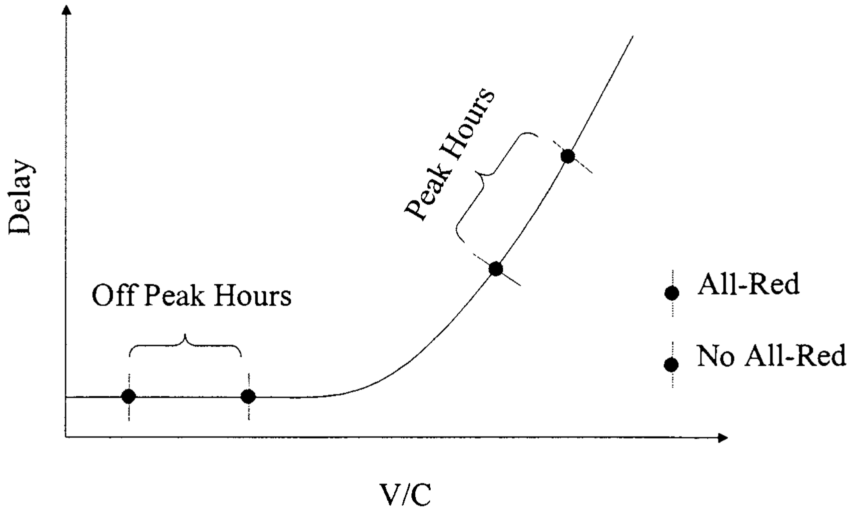


Figure 1.1: Conceptual Diagram of Intersection Delay and Volume to Capacity Ratio at Intersections With and Without the All-Red Clearance Interval

1.4 Thesis Organization

This thesis is organized into eight chapters. Chapter 1 introduces the reader to the background, research needs, objectives, and scope of research. Chapter 2 provides a literature review focused on safety implementations of the all-red clearance on vehicles, pedestrians, and bicyclists; signalized intersection capacity affects, and signal timing. Chapter 3 focuses on the use of all-red clearance interval at the state and local levels in the Midwest. A summary of the data collection, derivation, and site selection techniques is presented in Chapter 4. Chapter 5 contains descriptive statistics from the cross-section and before and after studies. The statistical models are results are presented in Chapter 6. A cost of implementation is presented in Chapter 7. Conclusions and recommendations are presented in Chapter 8.

Chapter 2: Background

Currently, it is almost standard practice in the United States to incorporate an all-red clearance interval into intersection signal design. Numerous research efforts have suggested that the use of all-red clearance intervals at signalized intersections may reduce intersection crashes, particularly those related to signal violations, and crashes involving pedestrians and bicyclists. However, other research has shown that an all-red clearance interval does not yield a reduction in crash rates.

2.1. Use of the All-Red Clearance Interval

The purpose of an all-red clearance interval is to allow additional time for motorists already in the intersection to clear the intersection on the red indication before conflicting traffic movements are released (FHWA, 2003). Generally, the duration of the all-red clearance interval is from 0.5 to 3.0 seconds.

2.2. Red Light Violations

In Minnesota and many other states, a red light violation is defined as any vehicle entering an intersection after the onset of the red light. A red light violation can be either deliberate or unintentional and is related to individual driver behavior but may also be affected by intersection characteristics as discussed in the following sections. Although this study does not specifically analyze violations, intersections with frequent violations are likely to experience more crashes.

2.2.1. Human Factors Affecting Decisions at Signalized Intersections

Red light violations are primarily a function of driver behavior. One of the major problems with determining the most effective way to stop red light violators is that there is not a specific category of individuals who habitually run red lights. Red light runners are drivers of all ages, economic classes, and gender (FHWA, 2003). An estimated, 47.8 percent of American drivers run red lights because they are in a hurry, not because they are under the influence of chemicals, unable to stop, or unable to see the red light (FHWA, 2003). The fact that almost half of red light violations are deliberate reduces the benefit of a all-red clearance interval.

Although the FHWA (2003) states there is not a specific category of red light violators, Retting et. al. makes some generalizations about characteristics of drivers who are more likely to run red lights. Red light runners are more likely to be younger, less likely to use seatbelts, have poorer driving records, drive smaller vehicles, and have multiple speed convictions (Retting, Williams, and Greene, 1998).

It is also believed that drivers who are familiar with a particular intersection are also familiar with the length of the yellow interval. They know to stop if the yellow phase is particularly short, or push the limits on a longer yellow phase (Datta, Schattler, and Datta, 2000).

Many studies have examined the effects of the all-red clearance interval for several months to a year before and after the implementation. Over time, if drivers become familiar with the presence and length of the all-red phase, they might push the limits trying to make it through the signal. If this the case, over a longer time period intersection crashes might return to pre implementation rates.

According to Moon et.al., approximately 30% of red light running crashes are caused by deliberate disobeying of red lights, and over 50% of red light running crashes can be attributed to driver unawareness of the signal status. If 80% of red light running crashes can be attributed to deliberate disobeying of signals and unawareness of signal status, providing an all red clearance interval can potentially only affect 20% of intersection crashes (Moon, Lee, and Park, 2003).

The number of red light violations is typically low during peak hour volumes because urban intersections are operating at or near capacity. This affects driver behavior. Consequently the majority of red light violations occur during off-peak hours because volumes are low, approach speeds are high, and traffic arrival is random (Datta, Schlattler, and Datta, 2000).

2.2.2. Operational and Geometric Factors Affecting Decisions at Signalized Intersections

Factors that affect the decision of a driver to either stop or proceed through an intersection include: the vehicle approach speed, color of the traffic signal, location of the vehicle with respect to the traffic signal when the yellow light is observed, weather conditions, pavement conditions, and vehicle type (Datta, Schlattler, and Datta, 2000).

The use of fully actuated, semi-actuated, and pre-timed signals was analyzed by the Highway Safety Information System to determine the effect of traffic control on red light running (2000). The number of red light running crashes for fully actuated signals was approximately 35 – 39 percent higher than those for pre-timed signals. This is possibly due to drivers anticipating the green at actuated signals, and expecting it to turn green for them.

A study conducted by the FHWA explored the effect of cross-street lanes, ADT, and traffic control and the relationship of these geometric features to intersection crash rates. The effect of the number of cross-street lanes on red light running crashes was evaluated by the Highway Safety Information System (2000). The researchers created a Negative-Binomial (N-B) model with controls for signal operation type, opposite street ADT, and left turn channelization. For each one-lane increase on the mainline (major road), there was a 7% increase in cross-street (minor road) red light running crashes. Interestingly, the increase in cross-street lanes did not have a significant effect on mainline red light running crashes. The number of mainline (major road) red light running crashes increased with higher mainline ADT and higher cross-street ADT. In addition, red light running crashes for the cross-street also increased with increasing cross-street ADT and mainline ADT. Two explanations can be proposed from this information. The first is that when there is higher ADT, there are fewer and shorter gaps in the cross street which causes more options for vehicle interaction. Because there are fewer and shorter gaps, the possibility for vehicle conflict increases for those running red lights. The other is that when there is an increase in vehicles approaching the signalized intersection, there are more opportunities for red light running crashes (Highway Safety Information System, 2000). There is a discrepancy between these findings of decreased red light violations of the previous study by Datta, Schlatter, and Datta (2000).

2.3. Effectiveness of the All-Red Clearance Interval

In order to reduce red violations, many jurisdictions have implemented an all-red clearance interval. Most studies have reported safety benefits from addition of the all-red clearance interval, but a handful of studies have produced mixed results. These findings are discussed in the following sections. Studies have focused on both the use and length of the all-red clearance interval.

2.3.1. Benefits of All-Red Clearance Interval

A study conducted in Detroit, Michigan compared red light violations at intersections where properly designed yellow and all-red intervals were added with intersections without all-red intervals. Fewer crashes were observed at signals with the all-red clearance interval. In addition, there was a reduction in right angle injury crashes at the treated intersections. It is important to note that all intersections studied in this before and after analysis were improved at the same time the all-red clearance interval was implemented, therefore results may not be wholly attributed to implementation of the interval. These improvements included:

- Increasing signal head size to 12-inches
- Yellow calculated on the basis of observed approach speed
- All-red clearance time based on the roadway geometry
- Exclusive painted left turn lanes at all approaches
- Exclusive left turn phases
- 4.0-seconds of yellow and 1.5 to 2 seconds of all-red
- Intersection approaches were repaved with asphalt
- Off-street parking was removed for 200-feet on all approaches
- All missing and deteriorated signs were replaced

(Datta, Schlattler, and Datta, 2000).

Since numerous improvements were made at the same time the all-red clearance interval was added, it is impossible to determine if the reduction in violations and right-angle injury crashes can be solely attributed to the addition of the all-red clearance interval.

2.3.2 Mixed Benefits of All-Red Clearance Interval

A before and after analysis was conducted in Oakland County, Michigan to determine the before and after impacts of red light violations and late exits when clearance intervals were calculated according to the ITE guidelines. In this study, a late exit is defined as entering the intersection during the time in which the signal changes to red. Three sites were chosen for analysis. Two of the intersections contained heavy traffic volumes and divided approaches, while the other intersection was a suburban, low volume intersection (Schlattler, Datta, and Hill).

Red light cameras were used to collect red light violations and late exit data for the through movement before and after implementation of the all-red clearance interval. The before period took place from October 2000 to February 2001 (4 months). The after period ranged from March 2001 to January 2002 (9 months). There were mixed results for reducing red light violations at the intersections, but the adequate clearance length was effective in reducing late exits. This indicates that use of the ITE recommended clearance interval timing might increase the safety for late exiting vehicles that are exposed to traffic before clearing the intersection.

In addition to the red light violations and late exit study, a before and after crash analysis was completed at the three intersections for two years before and two years after the signal retiming. All crashes within 150 feet of the intersections were included, although crashes directly related to driveways within this radius were omitted from the analysis. At the time of publication of the study, intersection crashes were reduced at the three study intersections, but no follow-up research is published on the final results (Schlattler, Datta, and Hill).

2.3.2. Disadvantages of All-Red Clearance Interval

A study conducted in Indiana took a different approach to evaluate the effectiveness of an all red clearance interval. Rather than looking at only the short term before and after effects of implementation of the all-red clearance interval, this study examined 2 years before and 2 to 4 years after implementation of the all-red clearance interval. In addition to conducting a long-term analysis, this study also used a comparison group, something that is generally not included in other studies. Also, three previous studies on the all-red clearance interval were reproduced with the Indiana data (Roper, et. al., 1990).

Intersections used in the study were chosen based on the availability of intersection crash data, date of implementation of all-red clearance, traffic volumes, and geometry (4-leg approach intersections with 2-way traffic). Twenty-eight intersections were chosen for the before and after analysis, and an additional 28 intersections were chosen for the comparison group. The authors suggest that the following items may impact the effectiveness of the all-red clearance interval, but were not considered:

- Length and adequacy of the all red interval
- Warrant for the all-red interval
- Existence or location of vehicle detectors
- Type of signal (fixed, semi, or fully actuated)

- Minor changes in signal phasing throughout the time period of the study
- Amount of lanes on the approach, including left turn lanes
- New development and or driveways near the intersections
- Discrepancies between travel speed and posted speed limit
- Changes in the traffic composition over the course of the study
- The Level of Service of the intersections or changes in the level of service of intersections

The first portion of this study involved examining intersection crash data for one and two years before and up to four years after the implementation of the all red clearance interval. The before and after periods were isolated by a one year period when the all-red clearance interval was implemented. During the one-year treatment period, the total crash rates, left turn crash rates, rear end crash rates, right turn crash rates, and right angle crash rates decreased. This immediate decrease in crash rates was attributed to the implementation of the all-red clearance interval. Although crash rates decreased initially, for the two years following the treatment year, crash rates increased to rates similar to or higher than the initial rates during the before period.

The second portion of the study compared the intersection crash rates of 28 intersections with the all-red clearance interval versus 28 intersections without the all-red clearance interval. In this portion of the study, each intersection was paired with an intersection based on entering AADT, approach speed, and angle of intersection. This comparison showed no significant difference in intersection crash rates between intersections with and without the all-red clearance interval.

Finally, three different studies were reproduced using the Indiana data. Just as they did in the before and after analysis, there was a treatment year separating the before and after periods to account for the sharp decline in crash rates immediately following the implementation of the all-red clearance interval.

The Indiana study concluded that the all-red clearance interval did not reduce crash rates after implementation. In addition, intersection crash rates for intersections with the all-red interval were not significantly lower than those without the all-red phase. Moreover, after reproducing three previous studies with the Indiana data and including the treatment year concept, several interesting conclusions were drawn. It was determined that the all-red clearance interval did not reduce injury crashes at intersections. Also, in cases the all-red clearance interval did reduce intersection crashes one year before and after, but not in the longer term. These findings coincide with the FHWA's view on the all-red clearance interval: "The red clearance interval is not intended to reduce the incidence of red light running; rather it is a safety measure" (FHWA, 2003).

2.3.4. Clearance Interval Length

Results from several studies indicate that clearance intervals (amber and or all-red clearance intervals) closer to the ITE recommended values can reduce red light violations. This reduction in red light violations can consequentially decrease right angle conflicts, thus increasing safety at intersections without the use of the all-red phase. The safety benefits can affect vehicles as well as pedestrians and bicycles.

2.3.4.1. Clearance Interval Length for Vehicles

A study conducted by Zador, Stein, Shapiro, and Tarnoff (1985) concluded that intersections with more adequate (longer) clearance intervals (amber and all-red clearance intervals) had fewer right angle and rear end crashes than intersections with inadequate clearance intervals.

Data was acquired from ninety-one intersections in eight different metropolitan areas: Chicago, Illinois; Denver, Colorado; Miami, Florida; Montgomery County, Maryland; Richmond, Virginia; San Diego, California; and White Plains, New York. These intersections were monitored for signal changes, vehicle speeds, and times through the use of a traffic data logging system developed by PRC Voorhees. The following six variables were chosen to analyze data:

- Cross-street Width
- Estimated Average Crossing Time
- Indirect Measures of Yellow Signal Timing
- Indirect Measures of Yellow and All-red
- ADT for Monitored Street
- Ratio of ADT to the Cross-street

Initially, the standard statistical procedure of cluster analysis was used to divide the ninety-one intersections into eight relatively uniform clusters. The average number of vehicles per second entering the intersection during the last four seconds of the green interval was defined as the base flow rate. An adjusted crash rate was computed for each approach. These eight clusters were then merged into five overlapping intersection cluster groups. The range in clearance interval times for the five cluster groups was 10% greater than recommended clearance interval timing to 10% less than recommended clearance interval timing. The clusters with shorter than recommended clearance interval timing experienced much higher crash rates than intersections with longer than recommended clearance intervals (Zador, Stein, Shapiro, and Tarnoff, 1985).

A study conducted by Retting et.al. (2000) explored whether the length of the all-red clearance interval had an effect on red light running. One hundred and twenty-two four legged intersections in Long Island, New York were chosen for analysis. Half of these intersections were chosen as control sites, while the other half were retimed using the ITE Clearance Interval Equations (ITE, 1994). These intersections were monitored for 36 months after the retiming of the signals. At the intersections with signals timed to ITE standards, there were 8% fewer reportable crashes (reportable crashes are crashes over $1000), 37% fewer pedestrian and bicycle crashes, and 12% fewer injury crashes. (Retting et.al. 2000) This study shows the strong safety impact of the longer clearance interval for pedestrians and bicyclists, in addition to the safety effect for motorists.

2.3.4.2. Clearance Interval Length for Pedestrians and Bicycles

As always, when designing intersection timing it is important to accommodate all intersection users including pedestrians and bicycles. At this point in time, there is little research in the area of the all-red clearance interval and it's affects on pedestrians and bicycles. It is believed that short amber phases should not be used at intersections where there is the potential for use by pedestrians and bicycles. In addition, some literature states that in some cases the all-red clearance interval may be necessary to accommodate pedestrians and bicycles at intersections (Watchel et.al., 1995 and Kochevar and Lalani, 1985).

2.4. Guidelines for Calculating the Duration of All-Red Clearance Interval

When agencies utilize the all-red clearance interval, there are different ways to select interval duration. Most Midwest agencies use the recommended ITE Guidelines, or a variation of the guidelines, and a few apply the equations presented in the "additional signal timing methods" section of this report.

2.4.1. ITE Guidelines

There are a variety of methods used to determine the length of the clearance interval. In this case the clearance interval is defined as the yellow change interval and possible all red clearance interval. Equations 2.1a and 2.1b from ITE are used to determine the change interval. Currently, this is the most common method used in the Midwest. These equations are based on an assumed driver perception reaction time of 1 second, a deceleration rate of 10 feet per second^2, and a vehicle length of 20 feet. The approach speed, percent grade, and intersection width are specific to the particular intersection.

The all-red clearance interval is a function of the width of the intersection, length of clearing vehicle, and approach speed.

Equation 2.1: ITE Method for Calculating All-Red Clearance Interval

Length of the Yellow Change Interval $= t + \frac{v}{(2a \pm 2Gg)}$ (a)

Length of the Yellow Change Interval (when all-red clearance intervals are not used) $= t + \frac{v}{(2a \pm 2Gg)} + \frac{(W+L)}{v}$ (b)

Where:
t = driver perception-reaction time for stopping, taken as 1s
v = approach speed, feet per second (meters per second), taken as the 85^{th} percentile speed
a = deceleration rate for stopping, taken as 10 feet per second^2 (3.0 meters/second^2)
g = percent grade, divided by 100
G = acceleration due to gravity 32.2 feet per second^2 (9.8 meters/second^2)
W = width of intersection, in feet (meters), measured from the upstream stop bar to the downstream extended edge of pavement
L = length of clearing vehicle, taken as 20 feet (6.1 meters)

(ITE, 1994)

2.4.2 Additional All-Red Clearance Interval Timing Methods

There are a few other accepted methods used in all-red clearance interval timing. They include the rule-of-thumb method, the use of the formula for a left-turn lane, and uniform value for the change interval. These methods of all-red clearance interval calculations are depicted in Equations 2.2.a, 2.2.b, and 2.2.c.

Equation 2.2: Additional Methods for Calculating the All-Red Clearance Interval

$$R = \frac{(w + L)}{v} \quad \text{(a)}$$

$$r = \frac{P}{v} \quad \text{(b)}$$

$$r = \frac{(P + L)}{v} \quad \text{(c)}$$

where:
r = length of the red clearance interval, to the nearest 0.1 second
w = width of the intersection, in feet (meters), measured from the near-side stop line to the far edge of the conflicting traffic lane along the actual vehicle path
P = width of intersection, in feet (meters), measured from the near-side stop line to the far side of the farthest conflicting pedestrian crosswalk along the actual vehicle path
L = length of vehicle, in feet (meters) assumed to be 20 feet (6 meters)
v = speed of the vehicle through the intersection, in feet /second (meters/second)

(ITE, 1994)

2.5. Alternative Solutions to the All-Red Clearance Interval

Retting et. al.(1998) conducted a study of two intersections in Arlington, VA. The study was conducted from November 1994 – March 1995, with the use of a microprocessor-based GATSO red-light camera. During the course of 2694 hours of surveillance of the intersection, 8121 red light violations took place. This equates to approximately three red light violations per hour. It is important to note that due to the nature of the equipment used, this value includes emergency response vehicles entering the intersection as well as right turns on red. The emergency response vehicles and right turn on red vehicles might have accounted for all of the violations, making the results of this study trivial. In addition, although precipitation was monitored it did not appear to have an impact of the number of red light violations. After conducting this study of the two intersections in Arlington, VA, some red light running countermeasures were suggested. These include: removal of unwarranted traffic signals, changing traffic signal timing, enforcement, and public support for the use of RLR cameras.

2.5.1. Extension of Yellow

Several studies both in the United States have evaluated extending the yellow phase and or retiming the yellow phase to match driver behavior at particular intersections. A study conducted in a medium sized city in New York explored the relationships between yellow phase length and red light violations, and all-red length and red light violations. Twenty sites were chosen for analysis. Three sets of data were manually collected. The first set of data was collected in October 1992. Red light violations were recorded for the existing signal phasing. Beginning in January, 1993, the following changes were applied to selected signalized intersections;

- The yellow interval was increased to meet ITE standards at four sites
- The all-red interval was increased at five sites to meet ITE standards
- Both the yellow and all-red intervals were increased to ITE standards at four intersections
- The remaining intersections did not experience any phase changes besides minor timing changes in conjunction with signal maintenance.

The second set of data was collected in April 1993. The signal timing was then changed back to the original October 1992 timing, and the third set of data was collected in

September and October 1993. The study concluded, "increasing the length of the yellow signal toward the ITE recommendations significantly decreased the chance of red light running and the length of the all-red interval did not seem to affect red light running" (Retting and Greene, 1997). This means that if signals were retimed to include the longer, more adequate yellow time, red light violations would significantly decrease. In addition, since the all-red clearance interval did not seem to affect red-light violations, an all-red clearance interval may not be necessary and the time saved by omitting it can increase the capacity of the intersection. If signals were retimed to include longer yellow time, this would have very important policy implications in the United States.

A study conducted in the Tuscon Metropolitan Area examined traffic characteristics during signal change intervals. Five intersections were chosen for analysis on the duration of the yellow change interval, effect of enforcement, and intersection approach grades. In order to obtain data, time-lapse photography was used. The cameras were able to detect vehicles within approximately 350 to 400 feet of the intersection. The study focused on the last vehicle to enter the intersection and the first vehicle to stop.

In part of this study, the yellow interval was extended from 2 to 4 seconds at two of the intersections, and was compared with two control intersections. For each of these intersections, descriptive statistics were computed for: approach speeds, distance from the intersection at the beginning of the yellow interval, response time, deceleration rate, and percent of vehicles entering on the red.

Results were mixed, however. At one of the intersections receiving the extended yellow, the average speed of the vehicles entering the intersection increased. Data from this intersection also showed that the vehicle's distance from the intersection at the beginning of the yellow interval was less when the yellow interval was extended to 4 seconds. At the other intersection, approach speeds, response time, and deceleration rate were lower after the extension of the yellow interval. It is important to note that at both intersections the number of vehicles entering the intersection after the onset of the red was reduced after the increase of the yellow interval. These findings were similar to those found by Stimpson, Zador, and Tarnoff (Wortman, Witkowski, and Fox, 1985).

2.5.2. Officer Enforcement

Officer enforcement of intersections is particularly difficult for a variety of reasons. The most dangerous difficulty for officer enforcement of intersections is that in most cases the officer will have to follow the vehicle into the intersection. This puts the officer and other drivers and passengers in danger. In addition, officer enforcement of intersections can be very expensive (Retting, Williams, and Greene, 1998).

2.5.3. Red-Light Running Cameras

To supplement officer enforcement of intersections, red light running cameras are being considered and used in some locations. One of the issues with red light running cameras is that the owner of the vehicle might not be driving when the red light is run. However, according to Retting, Williams, and Greene, several studies have shown almost all vehicles caught running red lights are driven by the vehicle owner or by someone in the same residence as the registered vehicle owner (1998).

According to the Insurance Institute for Highway Safety the installation of red light running cameras has greatly reduced red light running and intersection crashes. In a study in

Oxnard, California, nine red light running cameras were installed across the city. After the installation of these cameras, there was a 42 percent drop in red light violations across the entire city. As a result, there was a 29 percent reduction in injury crashes in the city. International studies have concluded that red light running cameras reduce red light violations by 40-50 percent and injury crashes by 25-30 percent (2003).

2.6. Summary of Findings

Several points can be made regarding the research on the effectiveness of the all-red clearance interval

- Most studies examined the short term effects of the all-red clearance interval
- Some studies showing drastic safety improvements have been performed on intersections that received other intersection safety improvements at the time of implementation of the all-red
- Other studies have shown mixed results after the addition of the all-red clearance interval
- A study by Purdue showed that the delay caused by the all-red clearance interval outweighed the safety benefits of implementing the all-red clearance interval

To address the fact that no consensus exists on the effectiveness of the all-red clearance interval on intersection crashes and violations, this study is conducted to assist jurisdictions in making informed decisions about the use of the all-red clearance interval.

Chapter 3: Midwest State and Local Practices

In order to determine Midwest state and local practices, state and local traffic engineering departments were contacted. Most states and cities in the Midwest follow or use a variation of the ITE guidelines to determine vehicle clearance intervals. All states and cities contacted used an all-red clearance interval at intersections. The only major exception to this rule is intersections containing older timing equipment that do not accommodate the all-red phase. The following sections outline the state and local practices for the use of the all-red clearance interval.

3.1. Use of All-Red Clearance Intervals at State Levels in the Midwest

All states contacted used some form of an all-red phase, but their methods for determining the duration of the red vary. The different methods are described in the following sections.

3.1.1. Illinois DOT

The Illinois DOT's policy on the use of the all-red clearance interval is outlined in the Bureau of Operations Traffic Policies and Procedures Manual (Illinois DOT, 1992). The difference between this equation and the ITE equations is that there is no consideration of grades on stopping distance. Grade adjustments are allowed if field observations deem them necessary. The length of the yellow interval should be the sum of the first two terms in equation 3.1 rounded up to a half second. The remainder of the time is allocated to the all-red interval. The range of acceptable yellow intervals is 3 to 5 seconds. When a yellow interval longer than 5 seconds is calculated for the yellow interval, the remaining time is assigned to the all-red interval.

Equation 3.1: Illinois DOT's Method for Calculating the All-Red Clearance Interval

$$Y + AR = t + \frac{v}{2a} + \frac{w + l}{v}$$

Where:

Y = length of yellow in seconds
AR = length of all-red in seconds
t = perception - reaction time of driver in seconds; the standard value is 1 second
v = approach speed in feet per second
a = deceleration rate in feet per second per second; 10 feet per second per second should be used
w = width of intersection in feet
l = length of vehicle in feet; the standard value is 20 feet

3.1.2. Indiana DOT

The Indiana Department of Transportation (INDOT) is divided into six districts. Although each district has its own discretion in dealing with signal timing, all six districts have agreed on a common method. The all-red period is used on all roads controlled by the INDOT, except intersections with older equipment not capable of handling the all-red phase. In these instances, the yellow time is lengthened up to the MUTCD maximum of 6 seconds (Tuttle, 2003, U.S. DOT, 2001).

In the state of Indiana, there are several purposes for the clearance interval. The first is to warn drivers the green interval is over and allow drivers who are far enough away from the intersection to stop. Another purpose of the clearance interval is to allow drivers who are unable to stop to clear the intersection. Finally, the clearance interval allows vehicles that illegally enter the intersection time to clear the intersection prior to the movement of traffic in conflicting lanes.

The clearance interval for through traffic is determined from tables provided by INDOT. The clearance intervals provided are based on equation 3.2. This equation is a modified "nondilemma zone" determination of clearance interval as denoted in the ITE *Transportation and Traffic Engineering Handbook* (ITE, 1999). The major difference is that the yellow time is determined by the initial velocity of vehicles on the roadway. This is either the posted speed limit, established speed from radar studies, or observed approach speed. The length of the all-red is determined by the speed of the vehicles entering the intersection. This is usually the same as the initial velocity, but sometimes differs based on a case-by-case basis.

The yellow interval on Indiana state highways is restricted to 3.0 to 5.1 seconds. The remainder of the clearance interval is included in the all-red interval. Indiana also has a special provision for heavy truck volumes. When there are heavy truck volumes, the vehicle length in the following equation is changed from 20 to 55 feet.

The Indiana DOT is aware of the study conducted by Purdue University, which concludes that intersection delay outweighs the safety impacts of the all-red clearance interval. However, they have decided to continue using the all-red phase "in order to provide the safest roadway system possible" (Tuttle, 2003).

Equation 3.2: Indiana DOT's Method for Calculating the All-Red Clearance Interval

$$\text{Clearance Interval} = t_p + \frac{v_i}{(2a + 2Gg)} + \frac{(w + l)}{v_c}$$

Where:

Clearance Interval = yellow + all-red

t_p = perception time, taken as 1 second

v_i = initial velocity, feet/second

a = deceleration rate for stopping, taken as 10 feet per second^2 (3.0 meters/second^2)

G = grade, percent

g = acceleration due to gravity 32.2 feet per second^2 (9.8 meters/second^2)

w = critical width of intersection, feet (meters), measured from the upstream stop bar to the downstream far edge of pavement

l = length of clearing vehicle, taken as 20 feet (6.1 meters)

v_c = velocity of the vehicle going through the intersection, feet/second

(Indiana DOT, 2002)

3.1.3. Minnesota DOT

The Minnesota DOT views the yellow interval as an indication for vehicles to come to a safe stop before entering the intersection or allows vehicles that cannot safely stop to clear the intersection prior to the onset of conflicting movements. The internal timing guidelines for the Minnesota DOT recommend using the ITE Guidelines for calculating the yellow and all-red clearance interval.

The Internal Timing Guidelines for the Minnesota DOT make it clear that the ITE Equations are only to be used as a guide for determining vehicle clearance times. Discretion is given to the traffic engineer to lengthen or shorten the clearance interval based on grade, truck traffic, intersection visibility, and intersection size. The maximum allowable all-red interval is 5.0 seconds (Minnesota DOT, 2002).

3.1.4. Missouri DOT

The Missouri DOT Phasing and Timing the Signal guidelines views the change and clearance interval as a necessary practice to clear intersections before reassigning right-of-way to conflicting movements (2003). The change period (yellow phase and all red) allows vehicles that are unable to stop to clear the intersection. In order to develop uniformity throughout the state, the Missouri DOT suggests that yellow change intervals range from 4 to 5 seconds. (The MUTCD suggests 3 to 6 seconds (MUTCD, 2001).

The Missouri DOT states, "The addition of an all-red clearance interval should not be automatically provided after every movement" (MoDOT). The use of an all-red clearance interval is reserved for situations when the needed change period is longer than yellow interval or where traffic engineers deem it is needed. There is generally a need at exceptionally wide intersections. By limiting the use of the all-red clearance interval, the Missouri DOT hopes to reduce the driver expectancy of the all-red clearance interval. The following equation is used to determine the length of the change interval. This equation is the same as the ITE equation for the Length of the Yellow Change Interval (when all-red clearance intervals are not used) except for the recommended deceleration values vary. Also, the MUTCD suggests using the 85^{th} percentile speed or prevailing speed limit to determine the change period, but the Missouri DOT also suggests using the 15^{th} percentile speeds. This lower speed will help accommodate wide intersections or left turns. Computing the equation with the 85^{th} and 15^{th} percentile speeds and using the more conservative value will provide safer intersections (MODOT, 2003).

Equation 3.3: Missouri DOT's Method for Calculating the All-Red Clearance Interval

$$CP = t + \frac{V}{(2a \pm 64.4g)} + \frac{(W+L)}{v}$$

Where:
CP = nondilemma change period (yellow plus all red), seconds
t = perception-reaction time, recommended as 1.0 s
V = approach speed, feet/second
g = percent grade (positive for upgrade, negative for downgrade)
a = deceleration rate, recommended values as follows:
- 10 ft/s2 - low speed approaches, i.e. CBD
- 12.5 ft/s2 - typical arterial approaches
- 15 ft/s2 - high speed approaches

W = width of intersection, ft
L = length of vehicle, recommended as 20 ft

NOTE: CP greater than 7 seconds not recommended.

Occasionally there are cases involving extremely steep grades or very high-speed approaches, causing the change period calculation to yield values larger than 7 seconds. When this occurs, the Missouri DOT suggests the use of advanced warning signs instead of lengthening the change period. This will increase the capacity of the intersection while maintaining signal-timing consistency throughout the state (MODOT, and Stotlemeyer, 2003).

3.1.5. Nebraska Department of Roads

Unlike the other Midwest DOTs, the Nebraska Department of Roads (NDOR) does not follow the ITE recommended practice for clearance intervals. This is because the state requires vehicles to stop at yellow lights. The NDOR has a policy calling for 4.5 to 5.0 seconds of yellow and 0.5 to 1.0 seconds of all red. The only city in the state using more than the recommended all red time is the city of Lincoln. Lincoln uses three seconds of all red in the central business district (Nebraska DOR, 2003).

3.1.6. Ohio DOT

The Ohio Department of Transportation Manual of Uniform Control Devices and Traffic Engineering Manual describes the use of the all-red clearance interval and the recommended length of yellow and all-red time. In the state of Ohio: "The exclusive function of the steady yellow interval shall be to warn traffic of an impending change in the right-of-way assignment." During this time vehicles should stop or proceed through the intersection if they are unable to stop. Most yellow vehicle change intervals range from three to six seconds depending on the speed of the approach traffic. In some instances the yellow change interval may be followed by an all-red interval. This all-red interval allows vehicle to clear the intersection prior to conflicting traffic movements entering the intersection. The typical maximum all-red interval is two seconds (Holstein, 2003).

The Ohio Department of Transportation Traffic Engineering Manual contains the following equation for determining the length of the clearance interval. It is important to note that all local agencies are required to follow the OMUTCD. The difference between this equation and that of the ITE recommended equations is that ITE has two equations: one when there is an all-red clearance interval and one when there is not an all-red clearance interval. The ODOT Traffic Engineering Manual also allows the engineer to account for start up time lost for conflicting movements in order to shorten the all-red phase for more efficient operations at busy intersections.

Equation 3.4: Ohio DOT's Method for Calculating the All-Red Clearance Interval

$$Y + AR = t + \frac{V}{(2a + 64.4g)} + \frac{W + L}{V}$$ English Units

$$Y + AR = t + \frac{V}{(2a + 19.6g)} + \frac{W + L}{V}$$ Metric Units

Where:
t = driver perception-reaction time for stopping, taken as 1s
v = approach speed, feet per second (meters per second)
a = deceleration rate for stopping, taken as 10 feet per second2 (3.0 meters/second2)
g = percent grade, divided by 100 (positive for upgrade, minus for downgrade)
W = width of intersection, in feet (meters), measured from the near Stop Line to the far edge of the conflicting traffic lane, along the actual vehicular path)
L = length of clearing vehicle, taken as 20 feet (6.0 meters)

(Holstein, 2003; Ohio DOT, 2003, and Ohio DOT, 2003)

3.2. Use of All-Red Clearance Intervals at Local Levels in the Midwest

Local policies for the all-red clearance interval were investigated. Traffic engineers from cities similar in size to Minneapolis were contacted and questioned about signal phasing practices on the local level. Following are summaries of the responses from traffic engineers in cities similar in size to Minneapolis.

Table 3.1 Midwest Cities Comparable in Size to Minneapolis

Midwest Cities Comparable in Size to Minneapolis

City	State	City Population	Metro Area Population
Bloomington *	Minnesota	85,182	2,968,806
Cincinnati	Ohio	311,258	1,646,395
Cleveland	Ohio	478,403	2,945,831
Columbus	Ohio	711,470	1,540,157
Lincoln	Nebraska	232,362	274,178
Milwaukee	Wisconsin	596,974	1,500,741
Minneapolis	**Minnesota**	**382,618**	**2,968,806**

* Bloomington, Minnesota was chosen because of it's close proximity to Minneapolis

Source: U.S. Census Bureau

(U.S. Census Bureau, 2003)

3.2.1. Bloomington, Minnesota

According to Chad Smith, traffic engineer for the City of Bloomington, Bloomington, Minnesota has all-red clearance intervals at almost all signalized intersections. The only exceptions are a handful of mid-block pedestrian crossings with old controllers that do not have the capability of containing an all-red phase. The city is currently in the process of updating these controllers and when complete, all signalized intersections in Bloomington will contain an all-red phase. Bloomington, Minnesota follows the Minnesota DOT guidelines for determining the length of all-red clearance intervals. This equation is the same as the ITE recommended length for an all-red interval.

Equation 3.5: Bloomington, Minnesota's Method of Calculating the All-Red Clearance Interval

$$R = \frac{w + L}{1.467\, v}$$

Where:
R = All-red clearance interval in seconds
w = Width of intersection, stop line to center of farthest conflicting lane
L = Vehicle length, assumed to be 20 feet
v = 85th Percentile speed in miles per hour
1.467 = Unit conversion factor

(Smith, 2003)

3.2.2. Cincinnati, Cleveland, and Columbus, Ohio

All local agencies in Ohio are required to follow the previously outlined guidelines for determining the all-red clearance interval contained in the OMUTCD (Holstein, 2003).

3.2.3. Lincoln, Nebraska

According to the Nebraska DOR, the City of Lincoln applies 3.0 seconds of all-red to all signals in the central business district regardless intersection design (2003).

3.2.4. Milwaukee, Wisconsin

The City of Milwaukee generally follows the ITE recommended signal-phasing equations as a guideline for the clearance interval at intersections. All intersections controllers with the capability for an all-red phase contain one. As a rule of thumb, most intersections within the city have 3.0 to 3.5 seconds of yellow (approximately one tenth of the speed limit), plus a minimum of 0.5 seconds of all-red. If an intersection had a speed limit of 30 mph, the yellow would be 3.0 seconds and there would be a minimum of 0.5 seconds of all-red. More complicated intersections (skewed, five-way, or extremely large) are sometimes allotted more yellow or all-red time. The maximum all-red used is 2.5 seconds (Weber, 2003).

3.3. Summary of All-Red Phasing in the Midwest

Most states and cities in the Midwest follow the ITE Guidelines or a variation of the ITE Guidelines for determining vehicle clearance interval length. Tables 3.2 and 3.3 summarize the methods for calculating clearance intervals used by several Midwest states and cities. In addition, Tables 3.2 and 3.3 depict the length of the amber interval, all-red clearance interval, and total clearance interval for an intersection with an approach speed of 30 miles per hour, 1% grade, and a 50-foot effective intersection width.

Table 3.2: Method of Calculating All-Red Clearance Intervals at State Levels

State	ITE Guidelines	Variation of ITE Guidelines	Other	Length of Amber Interval	Length of All-Red Interval	Total Length of Clearance Interval
Illinois		X		3.50	1.59	5.09
Indiana		X		1.52	1.59	3.11
Minnesota	X			1.52	1.59	3.11
Missouri		X		1.52	1.59	3.11
Nebraska			X	4.5 to 5	0.5 to 1.0	5 to 6
Ohio		X		1.52	1.59	3.11

Table 3.3: Method of Calculating All-Red Clearance Intervals at Local Levels

City	**ITE Guidelines**	**Variation of ITE Guidelines**	**Other**	**Length of Amber Interval**	**Length of All-Red Interval**	**Total Length of Clearance Interval**
Bloomington	X			1.52	1.59	3.11
Cincinnati		X		1.52	1.59	3.11
Cleveland		X		1.52	1.59	3.11
Columbus		X		1.52	1.59	3.11
Lincoln			X	N/A	3.00	N/A
Milwaukee			X	3.0 to 3.5	0.50	3.5 to 4.0

Chapter 4: Data Collection, Deviation, and Site Selection

Because intersection information was not readily available in electronic formats, an extensive intersection database was created for this project. The data was obtained from several sources from the City of Minneapolis. The completed intersection database for the cross-sectional and before and after analysis includes the following attributes:

- Intersection number (defined by the City of Minneapolis)
- Intersection name
- Treatment (all-red, no all-red)
- Date of addition of all-red
- Accuracy of the all-red clearance interval addition date was noted because the all-red clearance interval addition date was not available at all intersections
- Speed
- Signal mount (overhead or pedestal)
- Presence of lighting at the intersection
- Daily Entering Vehicles (DEV)
- All intersection crashes per year
- Relevant intersection crashes per year (head on, rear end, right angle, left turn, right turn, and side swipe)

Other intersection characteristics that were not investigated due to time constraints or data availability include:

- Intersection grade
- Presence of on-street parking

- Signal timing including length of the all-red clearance interval
- Number of approach lanes
- Type of signal (fixed versus fully or semi actuated)
- Intersection width
- Observed approach speeds versus posted speeds

In addition, whether or not an individual signal was warranted was not investigated although this might play a role in the number of drivers running red lights. The MUTCD cautions this is a consequence of signals that are perceived as unnecessary by the public.

4.1. Description of Study Area

The study area is Minneapolis, Minnesota. At the time of this study, there were 803 signalized intersections. Six hundred and ninety-nine of the signalized intersections had an all-red clearance interval while 104 did not.

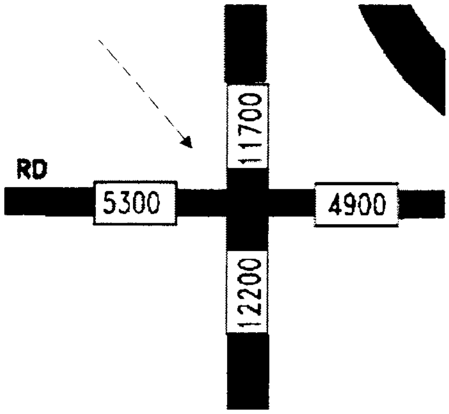
4.2. Usable Intersections

Only intersections of two-way roads with four approaches were analyzed. Skewed, offset, or intersections with horizontal curves on approaches were not used to eliminate the influence of geometry on study intersections. In order to identify acceptable locations, plans for all Minneapolis signalized intersections were examined resulting in 228 usable intersections for analysis. A usable intersection is an intersection with two-way roads with four approaches, and no skew, offset or horizontal curves. Thirty-eight of these intersections did not have an all-red clearance interval. Appendix Table A1 contains a list of usable intersections.

4.3. DEV at Each Intersection

Because traffic counts were not directly available for each intersection approach, AADTs were determined through a variety of methods. The first method used a vehicular traffic flow map obtained from the City of Minneapolis Transportation Division. If the street was not shown on this map, traffic was obtained from an AADT station history database obtained from the City of Minneapolis Transportation Division. All of the AADTs were not obtained from this database because it was more cumbersome to use and was not obtained until after the first method was complete. Finally, if neither source provided the counts of interest, AADT was estimated as an average of AADT on all Municipal Streets in Hennepin County.

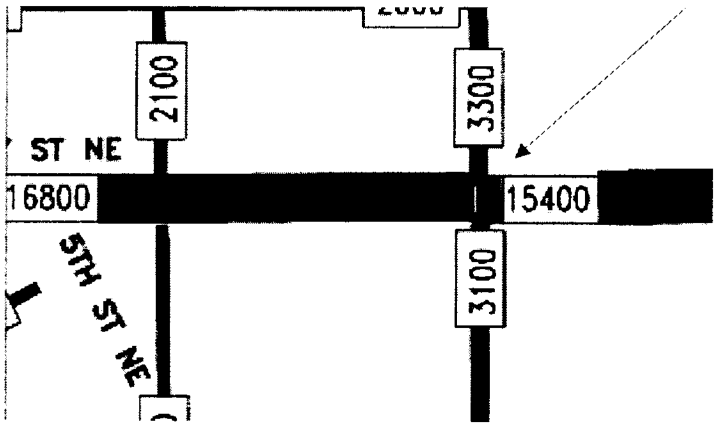
The first method of determining AADT for all usable intersection approaches involved utilizing the vehicular traffic flow map. Information was available for all 228 intersections' phase 2 (major) approaches using this method. In addition, information was available from the vehicular traffic flow map for 139 of the minor approaches. Several rules were followed to obtain AADT for approaches as depicted in Figures 4.1, 4.2, and 4.3.



Situation 1: AADT Information for Each Approach

DEV = (5300 + 11700 + 4900 +12200)/2

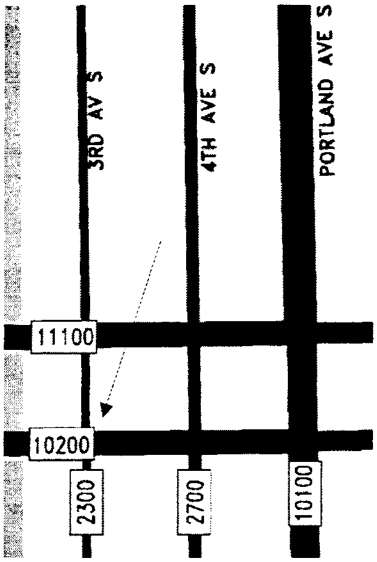
Figure 4.1: AADT Information for Each Approach



Situation 2: AADT Available for 3 Approaches,
And Information for 4th Approach Within Several Blocks

DEV = (3300 + 15400 + 3100 + 16800)/2

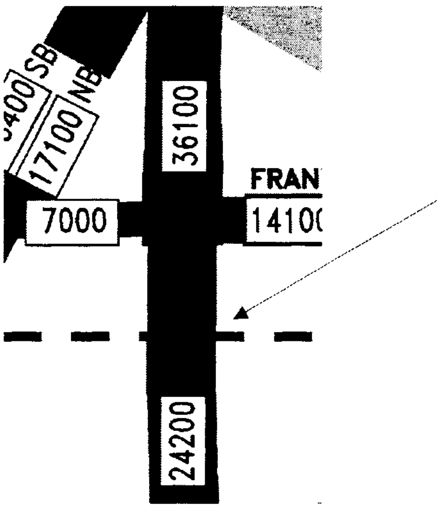
Figure 4.2: AADT Available for 3 Approaches, and Information for 4th Approach Within Several Blocks



Situation 3: AADT Information Available for Only 2 Approaches

DEV = (10200 x 2 + 2300 x 2)/2

Figure 4.3: AADT Information Available for Only 2 Approaches



Situation 4: Minor Approach is not on AADT Map

DEV = (24200 + 36100 + Either Database Values for Each Approach or Default of 600 for Each Approach)/2

Figure 4.4: Minor Approach is not on AADT Map

In some instances there was no AADT information for a phase 4 (or minor approach) intersection approach. Figure 4.4 depicts this scenario. In these cases, the AADT Station History Database was referred to determine the AADT on the minor approach. Just as in the previous diagrams, the locations of the count stations were determined, and the AADT was based on the same spatial parameters previously depicted in the figures. This occurred at 59 intersections.

If AADT information was not available from the map or database, VMT and miles of roadway for municipal streets in Minneapolis was used to estimate AADT. This occurred at 30 intersections. Using Equation 4.1 AADT was determined to be 607 VPD. The implication of using this estimate is that if actual volumes are higher than the estimate, the intersection might appear to have a higher crash rate than it is actually experiencing (the opposite is true if the estimate is too high). The three lowest AADT in the dataset are 300, 459, and 600. This means that the estimate of 607 VPD seems to be a reasonable estimate.

Equation 4.1: Determining Average Minneapolis AADT

$$AADT = \frac{DailyVMT}{\text{Miles of Roadway}}$$

Where:

$DailyVMT = 464{,}023$ for Minneapolis

Miles of Roadway = 764.9 for Minneapolis

Once AADT information was estimated for each intersection approach, intersection DEV was determined by taking the sum of all approaches and dividing by 2. This method was chosen because turning movements and other information such as AADT directional split was not available. Equation 4.2 depicts how DEV was determined for each intersection.

Equation 4.2: Determining DEV for Each Intersection

$$DEV = \frac{(AADT_1 + AADT_2 + AADT_3 + AADT_4)}{2}$$

Where:

$AADT_1$ = AADT on North Approach

$AADT_2$ = AADT on South Approach

$AADT_3$ = AADT on East Approach

$AADT_4$ = AADT on West Approach

After the DEV was determined at each intersection, a growth factor was applied to forecast DEV for each year in the study time frame. The Minnesota DOT State Aid Manual has a growth factor for each county, which can be used to prepare a 20-year forecast for growth. For Hennepin County, where Minneapolis is located, the growth factor is 1.4. Equation 4.3 can be used to annualize the growth factor.

Equation 4.3: Annualizing the Minneapolis Traffic Growth Factor

$$\text{Growth Factor for } y \text{ years} = (1 + i)^y$$

Where:

i = Annual Growth Factor for Minneapolis

y = Number of Years

If one annualizes this growth factor of 1.4 over 20 years, a 1.69% growth in traffic is expected each year. Initially, this 1.69% growth factor may sound low, but Minneapolis has been fully developed for many years, and one would not expect to see a significant increase in traffic on local streets. The growth factor was used to factor up or down DEV values at each study intersection over the course of the study period. For example, at most intersections DEV was calculated from the 2002 vehicular traffic flow maps and needed to be factored down for other years in the study to such as 2001, 2000, 1999, etc.

4.4. Approach Speed

Initially, it was assumed that approach speed would affect number of crashes at an intersection. However, all posted speed limits for the study area were 30 miles per hour. Although a number of approaches did not have posted speed limits, according to the Minnesota statutory speed laws, urban streets in the state of Minnesota have a speed limit of 30 miles per hour (Minnesota Department of Public Safety, 2001). Collection of actual speeds was beyond the scope of the project. Consequently, the impact of speed was not investigated.

4.5. Visibility of Signal Heads

In order to account for signal visibility, intersection plans were examined to determine whether there were overhead or pedestal signals on the Phase 2 and Phase 4 (major and minor) approaches. In order to accomplish this, two dummy variables were created: D1 and D2. Values were then assigned to D1 and D2 based on whether there were overhead signal or pedestal signals on the major and minor approaches. Table 4.1 depicts the method for coding the location of signals at study intersections.

Table 4.1: Method for Coding the Location of Signals at Study Intersections

D1 = 1 If there are overhead signals for both approaches
D1 = 0 Otherwise

D2 = 1 If there are overhead signals for one direction
D2 = 0 Otherwise

4.6. Presence of Intersection Lighting

Research is available on whether or not the presence of intersection lighting plays a role in decreasing crashes (Blythe, Box et. al., and Lipinski and Wortman). Many studies conclude that lighting decreases crashes at night in rural and urban settings. Since the presence of lighting might have an impact on intersection crashes, intersection plans were inspected to see if intersections had street lighting. Only the presence of intersection lighting was noted, as intensity data was not available for every intersection.

4.7. Crashes

Crash reports at each intersection were obtained from the City of Minneapolis Office of Transportation and Parking Services. Crashes were classified into 15 different categories. Of these fifteen categories, 6 groups were related to red light violations and or the absence or presence of the red light clearance interval (Roper, et. al.). These 6 categories are denoted with an asterisk (*).

- HO* Head On
- RE* Rear End
- RA* Right Angle
- LT* Left Turn
- SS* Side Swipe
- RT* Right Turn
- FO Fixed Object
- PV Parked Vehicle
- PKG Parking
- BKG Backing
- TRN Train
- PED Pedestrian
- BIC Bicycle
- OTH Other
- UNK Unknown

Relevant crashes and total crashes were determined for each year at each intersection under investigation.

4.8. Site Selection

In this study, three distinct types of analysis sites were considered: intersections historically (more than 4 years) operating with an all-red clearance interval, intersections historically operating without an all-red phase, and intersections where all-red clearance intervals were implemented between 1992 and 1996. Intersections historically operating with an all-red phase were compared to intersections operating without an all-red phase in a cross-sectional study. A before and after analysis was used to compare intersections in which all-red was implemented with a control group of intersections historically operating without the all-red clearance interval.

Two different studies were performed to determine the effectiveness of the all-red clearance interval. The first study was a cross-sectional study. The second study was a before and after analysis of intersections where all-red clearance intervals were added compared to a control group that operated without the all-red clearance interval.

4.8.1. Cross-Section Study

Seventy-six intersections were selected for cross-section analysis. This study examined two different groups of intersections: intersections historically operating with the all-red clearance interval and intersections historically operating without the all-red clearance interval.

There were 228 intersections with two-way approaches, four-legged approaches, no skew, offset, or horizontal curves. Thirty-eight of these intersections had no all-red clearance interval. All 38 of these intersections were used in the cross-section study.

In order to select intersections with the all-red clearance interval, the remaining 190 intersections were considered. First, they were sorted according to the date of implementation of the all-red clearance interval. In order to avoid any possible immediate or short-term effects of the addition of the all-red clearance interval, only intersections with an all-red addition prior to 1996 were eligible for use in the study. Intersections converted to operating with an all-red clearance interval after 1996 were ineligible for this study.

The remaining intersections were then sorted in ascending order by their numerical identifier that was provided by the City of Minneapolis. Microsoft Excel's Random Number Generator was used to select the 38 random intersections with all-red clearance intervals. Figure 4.5 is a map of all of the intersections used in the cross-section study. Table 4.2 lists the intersections used in the cross-section study. A complete intersection database for the cross-section study is located in the Appendix Table A2.

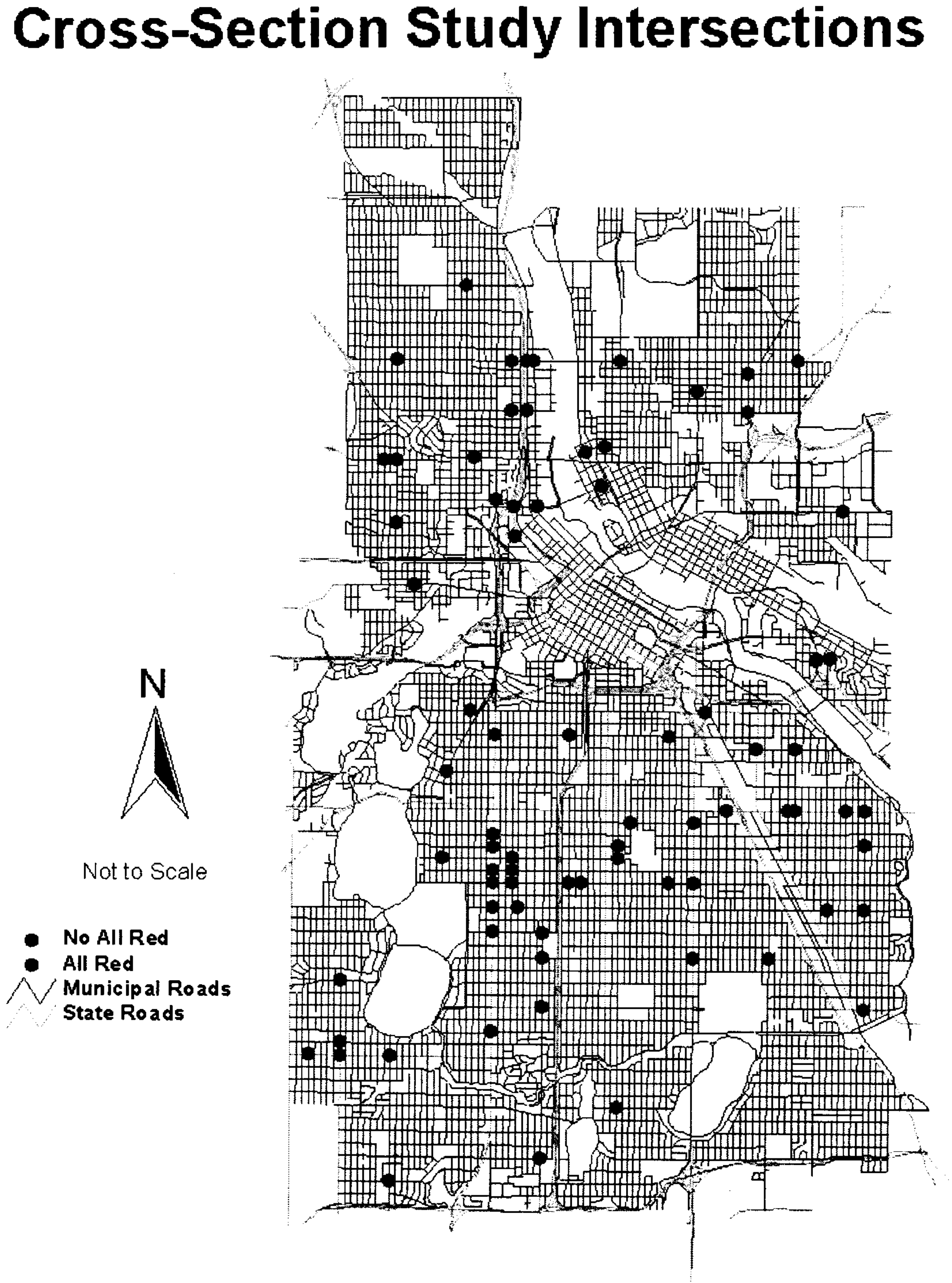


Figure 4.5: Map of Intersections used in the Cross-Section Study

Table 4.2: Intersections Used in the Cross-Section Study

NUM	INTERSECTION NAME	A-R	A-R_Add
26	E Lake St & 42 Ave S	N	N/A
28	E 31 St & 10 Ave S	N	N/A
34	Lyndale Ave S & W 40 St	N	N/A
52	Cedar Ave & E 36 St	N	N/A
74	W 50 St & Penn Ave S	N	N/A
112	E 25 St & 31 Ave S	N	N/A
116	E Lake St & 39 Ave S	N	N/A
150	Chicago Ave & E 33 St	N	N/A
176	Washington Ave N & 26 Ave N	N	N/A
177	E Hennepin Ave & Hoover St	N	N/A
203	E Franklin Ave & Cedar Ave	N	N/A
227	26 Ave S & E 25 St	N	N/A
231	Central Ave NE & 20 Ave NE	N	N/A
267	Nicollet Ave & 58 St	N	N/A
268	Huron Blvd & Fulton St	N	N/A
299	Grand Ave & W 34 St	N	N/A
339	Plymouth Ave & 2 St N	N	N/A
345	Lyndale Ave N & 14 Ave N	N	N/A
361	3 Ave S & E 24 St	N	N/A
368	Lyndale Ave S & W 48 St	N	N/A
389	27 Ave SE & Essex St	N	N/A
463	Lyndale Ave S & W 38 St	N	N/A
468	Nicollet Ave & 42 St	N	N/A
469	Nicollet Ave & 40 St	N	N/A
490	W 35 St & Grand Ave	N	N/A
497	W 36 St & Grand Ave	N	N/A
499	W Broadway & Dupont Ave N	N	N/A
577	Penn Ave N & 12 Ave N	N	N/A
791	Xerxes Ave S & W 44 St	N	N/A
797	Penn Ave N & Golden Valley Rd	N	N/A
837	Lyndale Ave S & W 32 St	N	N/A
841	Cedar Ave & E 42 St	N	N/A
870	42 Ave S & E 38 St	N	N/A
919	E 38 St & 36 Ave S	N	N/A
942	26 Ave N & 4 St N	N	N/A
970	42 Ave S & E 33 St	N	N/A
975	Xerxes Ave S & W 49 St	N	N/A
981	Glenwood Ave & Morgan Ave N	N	N/A
43	W 50 St & Chowen Ave S	Y	4/14/80
51	Lyndale Ave S & W 24 St	Y	2/13/84
75	Lowry Ave N & Penn Ave N	Y	12/5/86
109	E Lake St & 31 Ave S	Y	11/9/62

121	W 50 St & Xerxes Ave S	Y	4/14/80
125	Chicago Ave & E 34 St	Y	6/16/72
233	Lyndale Ave N & Plymouth Ave	Y	10/21/80
237	10 Ave N & 5 St N	Y	6/9/80
265	Lowry Ave N & 4 St N	Y	12/12/75
272	Washington Ave N & Lowry Ave N	Y	3/12/81
298	W Franklin Ave & Dupont Ave S	Y	2/11/87
349	Lyndale Ave S & W 36 St	Y	7/14/81
355	Lyndale Ave S & W 33 St	Y	11/4/76
412	Hennepin Ave & W 34 St	Y	9/6/79
439	E Lake St & 22 Ave S	Y	12/3/86
441	Dowling Ave & Emerson Ave N	Y	1/13/82
459	Cedar Ave & E 31 St	Y	8/26/87
467	Hennepin Ave & W 27 St	Y	5/21/84
478	Stinson Pkwy & Lowry Ave NE	Y	9/21/79
486	Bloomington Ave & E 36 St	Y	6/2/70
572	W 38 St & Pleasant Ave	Y	3/27/85
582	E 36 St & 4 Ave S	Y	9/23/81
783	E 46 St & 42 Ave S	Y	9/20/72
809	Johnson St & 18 Ave NE	Y	11/18/87
851	Johnson St & 23 Ave NE	Y	7/30/74
855	Marshall St & 13 Ave NE	Y	3/5/81
860	Lowry Ave & University Ave NE	Y	3/8/51
861	Nicollet Ave & 46 St	Y	3/27/81
864	2 St NE & 13 Ave NE	Y	11/20/70
865	E 36 St & 3 Ave S	Y	8/12/83
873	E Lake St & 30 Ave S	Y	10/22/86
886	Bloomington Ave & E 24 St	Y	11/16/81
897	Lowry Ave N & 2 St N	Y	6/2/86
898	8 Ave NE & Marshall St	Y	9/26/85
914	Lyndale Ave S & W 35 St	Y	1/9/67
943	Penn Ave S & W 60 St	Y	6/10/69
969	Golden Valley Rd & Russell Ave	Y	7/18/72
980	28 Ave S & E 42 St	Y	4/18/75

4.8.2. Before and After Study

Intersections were selected to support a before and after study, requiring data for 5 years before, 5 years after and one year during the implementation of the all-red. The analysis period chosen was to be 1987 to 2002. Two different groups of intersections were selected. The first group of intersections was a treatment group. The second was a control group operating without the all-red clearance interval for the duration of the study period.

There were 22 intersections in the treatment group. All 22 intersections were converted to all-red clearance operation between 1991 and 1997. These 22 intersections comprise all two-way, four-leg intersections without skew, offsets, or horizontal curves in the city of Minneapolis converted to the all-red clearance interval operation between 1991 and 1997. Eleven years of crash data were obtained for each intersection: 5 years before, 5 years after, and 1 year during the implementation of the all-red clearance interval.

The control group of intersections included 47 intersections. These 47 intersections operated without the all-red clearance interval from 1985 until at least January 1, 2003. Crash data from 1987 – 2002 were obtained for each intersection in the control group. The locations of the intersections used in the before and after study are illustrated in Figure 4.6. Table 4.3 lists the intersections used in the before and after study. A complete intersection database for the before and after study can be found in the Appendix Table A3.

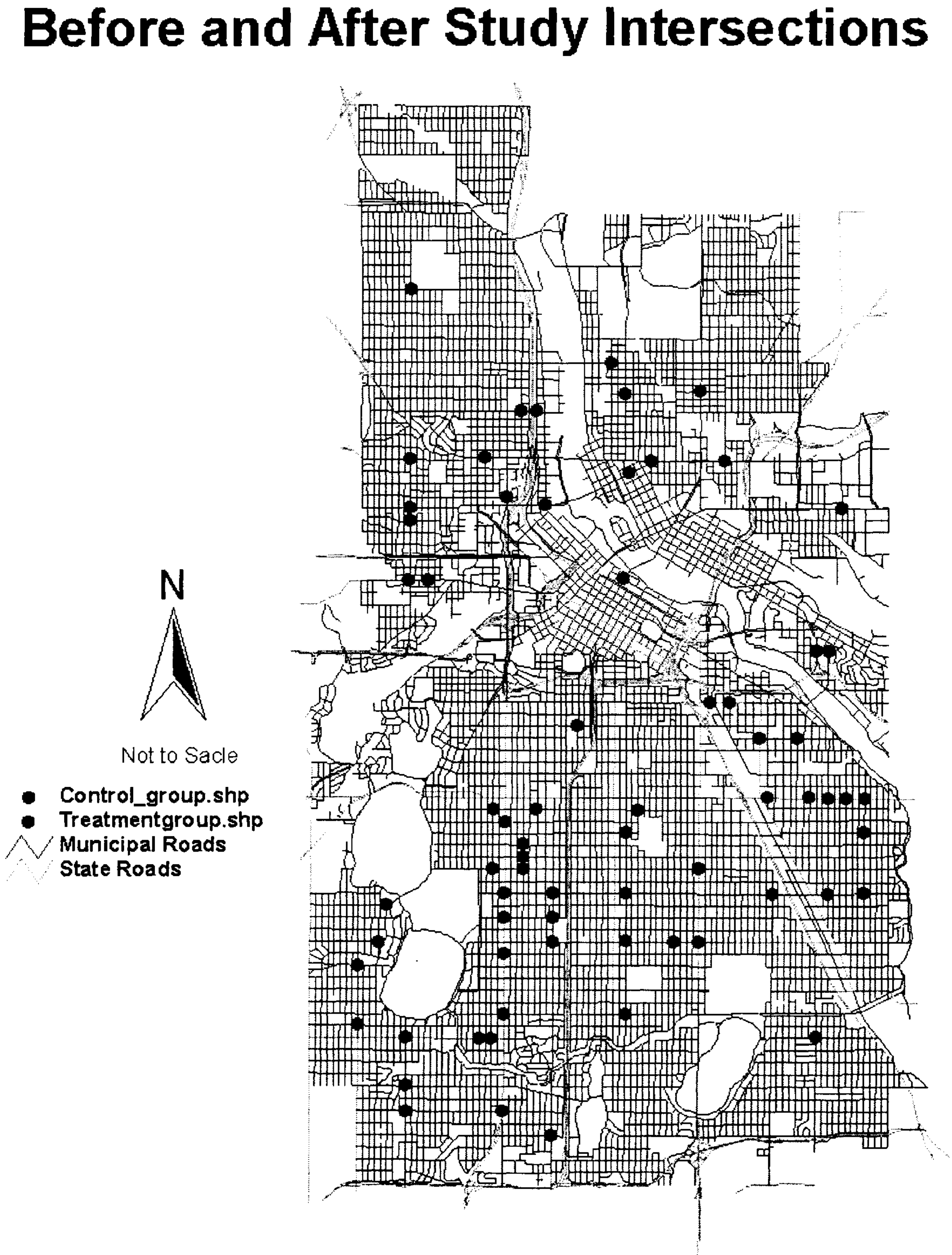


Figure 4.6: Map of Intersections Used in the Before and After Study

Table 4.3: Intersections in the Before and After study

NUM	INTERSECTION NAME	A-R	A-R_Add	Group
981	Glenwood Ave & Morgan Ave N	N	N/A	Ctrl
975	Xerxes Ave S & W 49 St	N	N/A	Ctrl
970	42 Ave S & E 33 St	N	N/A	Ctrl
942	26 Ave N & 4 St N	N	N/A	Ctrl
919	E 38 St & 36 Ave S	N	N/A	Ctrl
870	42 Ave S & E 38 St	N	N/A	Ctrl
841	Cedar Ave & E 42 St	N	N/A	Ctrl
837	Lyndale Ave S & W 32 St	N	N/A	Ctrl
797	Penn Ave N & Golden Valley Rd	N	N/A	Ctrl
791	Xerxes Ave S & W 44 St	N	N/A	Ctrl
577	Penn Ave N & 12 Ave N	N	N/A	Ctrl
499	W Broadway & Dupont Ave N	N	N/A	Ctrl
497	W 36 St & Grand Ave	N	N/A	Ctrl
490	W 35 St & Grand Ave	N	N/A	Ctrl
469	Nicollet Ave & 40 St	N	N/A	Ctrl
468	Nicollet Ave & 42 St	N	N/A	Ctrl
463	Lyndale Ave S & W 38 St	N	N/A	Ctrl
389	27 Ave SE & Essex St	N	N/A	Ctrl
368	Lyndale Ave S & W 48 St	N	N/A	Ctrl
361	3 Ave S & E 24 St	N	N/A	Ctrl
345	Lyndale Ave N & 14 Ave N	N	N/A	Ctrl
339	Plymouth Ave & 2 St N	N	N/A	Ctrl
299	Grand Ave & W 34 St	N	N/A	Ctrl
268	Huron Blvd & Fulton St	N	N/A	Ctrl
267	Nicollet Ave & 58 St	N	N/A	Ctrl
231	Central Ave NE & 20 Ave NE	N	N/A	Ctrl
227	26 Ave S & E 25 St	N	N/A	Ctrl
203	E Franklin Ave & Cedar Ave	N	N/A	Ctrl
177	E Hennepin Ave & Hoover St	N	N/A	Ctrl
176	Washington Ave N & 26 Ave N	N	N/A	Ctrl
150	Chicago Ave & E 33 St	N	N/A	Ctrl
116	E Lake St & 39 Ave S	N	N/A	Ctrl
112	E 25 St & 31 Ave S	N	N/A	Ctrl
74	W 50 St & Penn Ave S	N	N/A	Ctrl
52	Cedar Ave & E 36 St	N	N/A	Ctrl
34	Lyndale Ave S & W 40 St	N	N/A	Ctrl
28	E 31 St & 10 Ave S	N	N/A	Ctrl
26	E Lake St & 42 Ave S	N	N/A	Ctrl
356	W 36 St & Bryant Ave S	Y	4/8/03	Ctrl
736	3 Ave S & 2 St S	Y	5/5/03	Ctrl
17	Penn Ave N & Glenwood Ave	Y	5/5/03	Ctrl
598	Bloomington Ave & E 42 St	Y	5/8/03	Ctrl
892	34 Ave S & E 50 St	Y	5/14/03	Ctrl

9	W 31 St & Bryant Ave S	Y	5/19/03	Ctrl
872	E Lake St & 33 Ave S	Y	5/28/03	Ctrl
261	Nicollet Ave & 38 St	Y	5/29/03	Ctrl
115	E Lake St & 36 Ave S	Y	6/27/03	Ctrl
97	Lowry Ave NE & 2 St NE	Y	7/10/91	Trt
938	E Franklin Ave & 22 Ave S	Y	7/11/91	Trt
600	Broadway St NE & Washington St	Y	7/26/91	Trt
2	W 50 St & Bryant Ave S	Y	8/27/91	Trt
388	Upton Ave S & W 43 St	Y	7/30/93	Trt
983	W 39 St & Sheridan Ave S	Y	8/13/93	Trt
751	Chicago Ave & E 48 St	Y	9/2/93	Trt
82	University Ave NE & 20 Ave NE	Y	9/20/93	Trt
882	Penn Ave S & W 54 St	Y	5/27/94	Trt
482	Plymouth Ave & Penn Ave N	Y	7/14/94	Trt
966	Penn Ave N & Dowling Ave	Y	7/27/94	Trt
832	Chicago Ave & E 42 St	Y	11/12/94	Trt
895	Broadway St NE & Fillmore St	Y	12/29/94	Trt
342	E Lake St & 27 Ave S	Y	1/3/95	Trt
162	Chicago Ave & E 38 St	Y	3/16/95	Trt
920	E 38 St & 28 Ave S	Y	3/23/95	Trt
68	Lyndale Ave S & W 56 St	Y	10/3/95	Trt
5	W 50 St & Dupont Ave S	Y	10/5/95	Trt
902	Penn Ave S & W 56 St	Y	12/22/95	Trt
900	University Ave NE & 8 Ave NE	Y	7/13/96	Trt
810	Lyndale Ave S & W 43 St	Y	5/1/97	Trt
989	W 31 St & Pillsbury Ave	Y	6/4/97	Trt

Chapter 5: Graphs and Trends

5.1. Cross-Section Study

The purpose of the cross-section study was to determine if there is a difference in the number of crashes or crashes rates at two different groups of intersections: one group historically operating with the all-red clearance interval and one group historically operating without the all-red clearance interval.

Four different methods of displaying the data for the cross-section study are presented in the following sections:

- Total crashes
- Relevant crashes
- Total crash rate
- Relevant crash rate

As mentioned earlier, relevant crashes include: head on, rear end, right angle, left turn, right turn, and side swipe crashes. The following graphs and tables show that intersections without the all red interval have lower total crashes, relevant crashes, total crash rates, and relevant crash rates, in this chapter there are no adjustments for differing characteristics between the two groups of intersections. Table 5.1 contains the descriptive statistics for the two groups of intersections. From the descriptive statistics, it appears that both groups of intersections are relatively similar with regard to DEV, D2, and intersection lighting. Both total crashes and relevant crashes are much higher at intersections with the all-red clearance interval.

Table 5.1: Descriptive Statistics for Characteristics of Cross-Section Study Intersections

		No All-Red	All-Red	Percent Difference
Total Crashes	Average	3.32	5.76	73%
	Standard Deviation	3.71	5.10	
Relevant Crashes	Average	2.09	4.02	92%
	Standard Deviation	2.91	4.03	
DEV	Average	13,278	16,105	21%
	Standard Deviation	6,484	6,087	
D1	Average	0.11	0.21	100%
D2	Average	0.37	0.34	-7%
Lights	Average	0.89	0.92	3%

5.1.1. Total Crashes

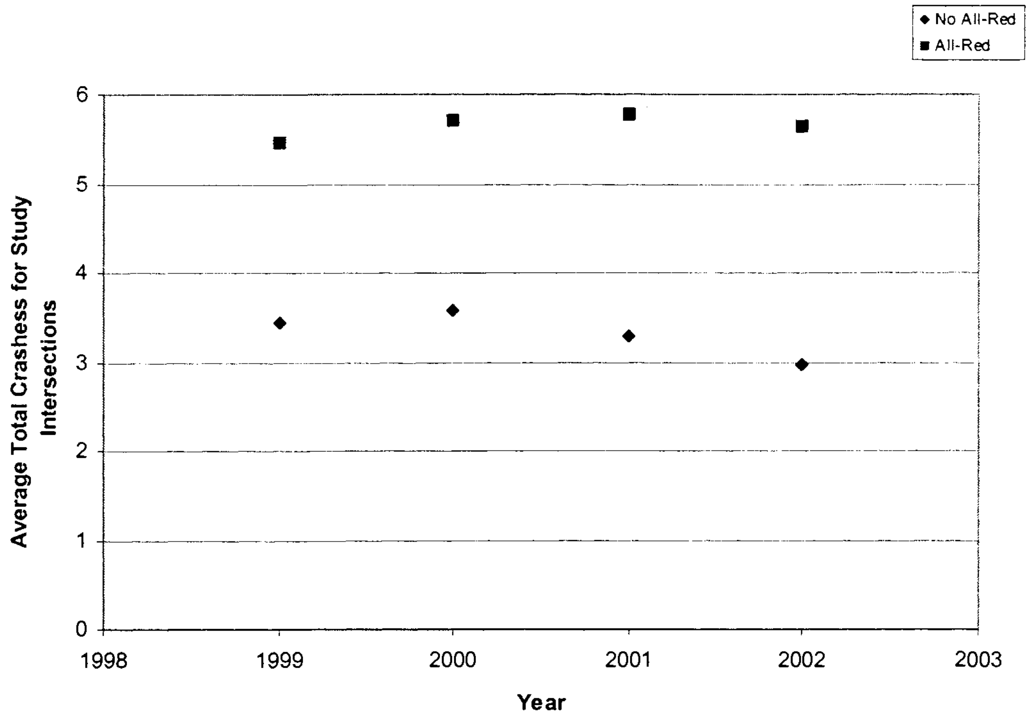


Figure 5.1: Average Total Crashes for Cross-Section Study Intersections

Table 5.2: Descriptive Statistics for Total Crashes at Cross-Section Study Intersections

	1999		2000		2001		2002		1999-2002	
	No A-R	**A-R**	**No A-R**	**A-R**	**No A-R**	**A-R**	**No A-R**	**A-R**	**No A-R**	**A-R**
Average	3.45	5.58	3.58	5.82	3.29	5.89	2.97	5.74	3.32	5.76
Minimum	0	0	0	0	0	0	0	0	0	0
Maximum	24	22	21	21	18	23	17	20	24	23
Median	2	5	3	5	3	4	2	4	2	4
Standard Deviation	4.43	5.40	3.58	5.10	3.34	5.28	3.49	4.82	3.71	5.10
Variance	19.66	29.12	12.79	25.99	11.18	27.88	12.19	23.28	13.72	26.05

No A-R: Intersections without the all-red clearance interval

A-R: Intersections with the all-red clearance interval

5.1.2. Relevant Crashes

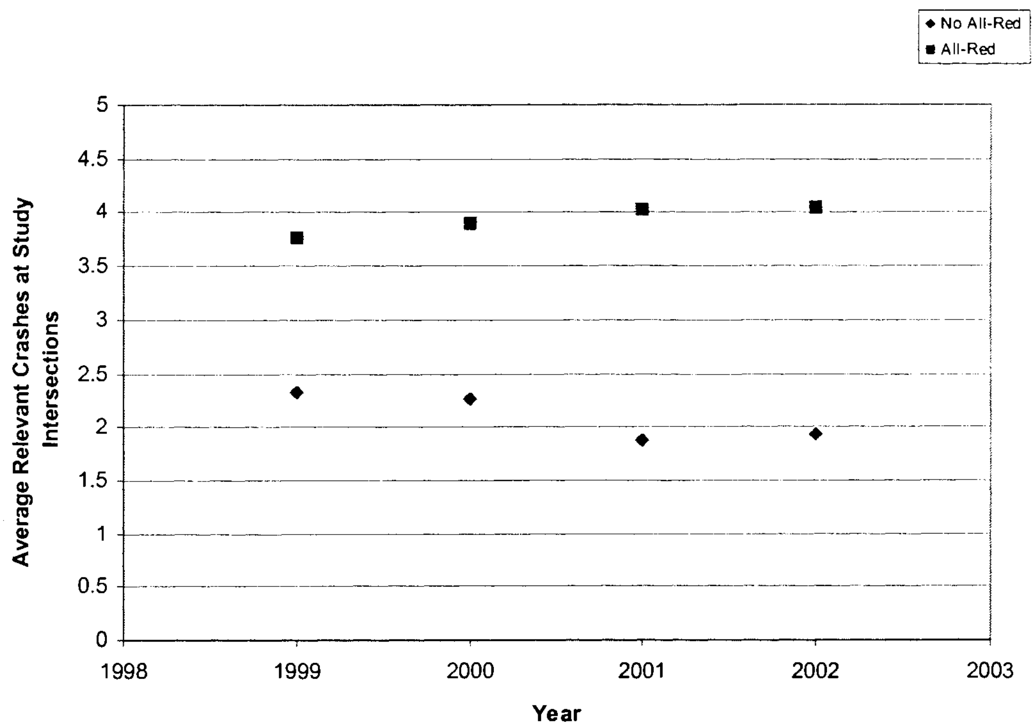


Figure 5.2: Average Relevant Crashes for Cross-Section Study Intersections

Relevant Crashes: head on, rear end, right angle, left turn, right turn, and side swipe

Table 5.3: Descriptive Statistics for Relevant Crashes at Cross-Section Study Intersections

	1999		2000		2001		2002		1999-2002	
	No A-R	A-R	No A-R	A-R	No A-R	A-R	No A-R	A-R	No A-R	A-R
Average	2.32	3.87	2.26	3.97	1.87	4.11	1.92	4.13	2.09	4.02
Minimum	0	0	0	0	0	0	0	0	0	0
Maximum	21	18	17	16	12	21	14	14	21	21
Median	1	3	2	3	1	2	1	3	1	3
Standard Deviation	3.68	4.29	2.83	3.75	2.36	4.58	2.69	3.57	2.91	4.03
Variance	13.57	18.44	8.04	14.08	5.58	21.02	7.21	12.71	8.47	16.24

No A-R: Intersections without the all-red clearance interval

A-R: Intersections with the all-red clearance interval

Relevant Crashes: head on, rear end, right angle, left turn, right turn, and side swipe

5.1.3. Total Crash Rate

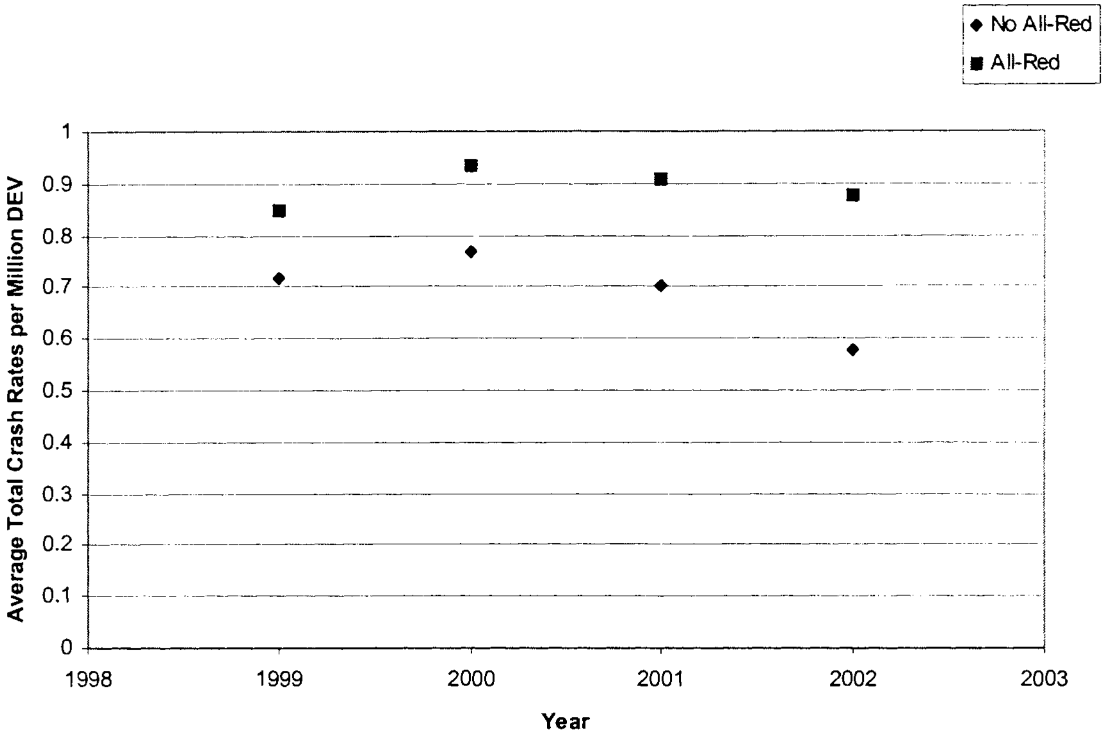


Figure 5.3: Average Total Crash Rates for Cross-Section Study Intersections

Table 5.4: Descriptive Statistics for Total Crash Rates at Cross-Section Study Intersections

	1999		**2000**		**2001**		**2002**		**1999-2002**	
	No A-R	**A-R**	**No A-R**	**A-R**	**No A-R**	**A-R**	**No A-R**	**A-R**	**No A-R**	**A-R**
Average	0.719	0.86	0.766	0.941	0.702	0.922	0.578	0.88	0.691	0.901
Minimum	0	0	0	0	0	0	0	0	0	0
Maximum	2.195	2.7	1.89	2.41	2.16	2.01	1.71	1.87	2.2	2.7
Median	0.495	0.803	0.692	0.874	0.613	0.848	0.452	0.921	0.582	0.863
Standard Deviation	0.624	0.63	0.483	0.608	0.534	0.595	0.505	0.533	0.538	0.587
Variance	0.389	0.396	0.233	0.369	0.285	0.354	0.255	0.284	0.29	0.345

No A-R:	Intersections without the all-red clearance interval
A-R:	Intersections with the all-red clearance interval
Crash Rate:	Per million Daily Entering Vehicle

5.1.4. Relevant Crash Rate

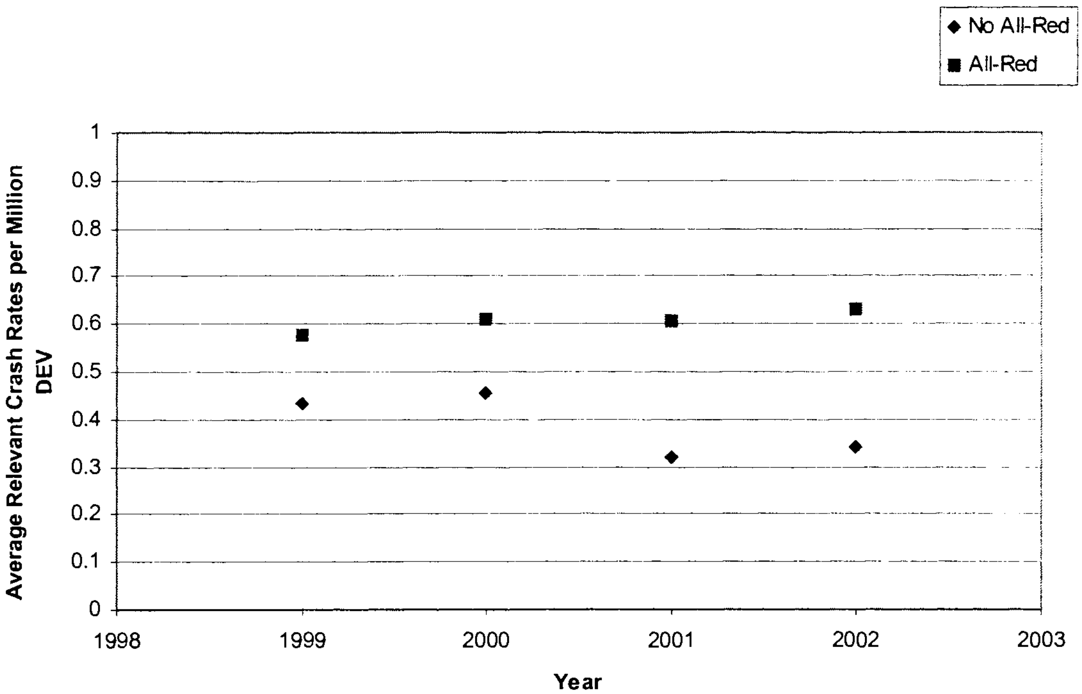


Figure 5.4: Average Relevant Crash Rates for Cross-Section Study Intersections
Relevant Crashes: head on, rear end, right angle, left turn, right turn, and side swipe

Table 5.5: Descriptive Statistics for Relevant Crash Rates at Cross-Section Study Intersections

	1999		2000		2001		2002		1999-2002	
	No A-R	A-R	No A-R	A-R	No A-R	A-R	No A-R	A-R	No A-R	A-R
Average	0.433	0.589	0.4558	0.618	0.3187	0.611	0.3391	0.637	0.3865	0.614
Minimum	0	0	0	0	0	0	0	0	0	0
Maximum	1.921	2.208	1.529	1.93	1.061	1.835	1.223	1.633	1.921	2.208
Median	0.308	0.412	0.424	0.594	0.259	0.411	0.263	0.669	0.336	0.508
Standard Deviation	0.452	0.556	0.376	0.484	0.301	0.54	0.335	0.426	0.371	0.499
Variance	0.204	0.309	0.141	0.234	0.091	0.292	0.112	0.182	0.138	0.249

No A-R: Intersections without the all-red clearance interval
A-R: Intersections with the all-red clearance interval
Relevant Crashes: head on, rear end, right angle, left turn, right turn, and side swipe
Crash Rate: Per million Daily Entering Vehicle

5.1.5. Cross-Section Study Conclusions

In the cross-section study, the descriptive statistics show that intersections without the all-red clearance interval have lower total crashes, relevant crashes, total crash rates, and relevant crash rates. It is important to note that the data are not adjusted for differences in volumes and other intersection characteristics that might affect the number of crashes. The models in the following chapter account for these characteristics in their calculations.

5.2. Before and After Study

The goal of the before and after study was to evaluate a treatment group of intersections for five years before they received the all-red clearance interval and five years after they receive the all-red clearance interval, with a one year treatment year in-between. The treatment group was compared to a control group of intersections that does not have the all-red clearance interval. There are 22 intersections in the treatment group and 47 intersections in the control group.

Four different methods of displaying the data for the before and after study are contained in the following sections:

- Total crashes
- Relevant crashes
- Total crash rate
- Relevant crash rate
- Relevant crash rates for individual intersections are located in Appendix A

Relevant crashes include: head on, rear end, right angle, left turn, right turn, and side swipe crashes. Table 5.6 contains the descriptive statistics for the treatment and control intersection groups for the before and after analysis. From the descriptive statistics, it appears that both groups of intersections are relatively similar with regard to DEV, D2, and intersection lighting. Both total crashes and relevant crashes are higher at treatment group intersections. Additionally, there are more intersections in the treatment group that have overhead signals for all approaches.

Table 5.6: Descriptive Statistics for Characteristics of Before and After Study Intersections

		Control Group	Treatment	Percent Difference
Total Crashes	Average	3.32	4.14	25%
	Standard Deviation	3.15	3.35	
Relevant Crashes	Average	2.10	2.93	40%
	Standard Deviation	2.34	2.92	
DEV	Average	12,150	13,130	8%
	Standard Deviation	5,492	3,155	
D1	Average	0.09	0.05	-47%
D2	Average	0.38	0.41	7%
Lights	Average	0.89	0.95	7%

After reviewing the following graphs, trends, and descriptive statistics tables, it appears that in the first year following the addition of the all-red clearance interval, intersection crashes are reduced. After the first year, crashes and crash rates appear to return to pre-implementation levels.

5.2.1. Total Crashes

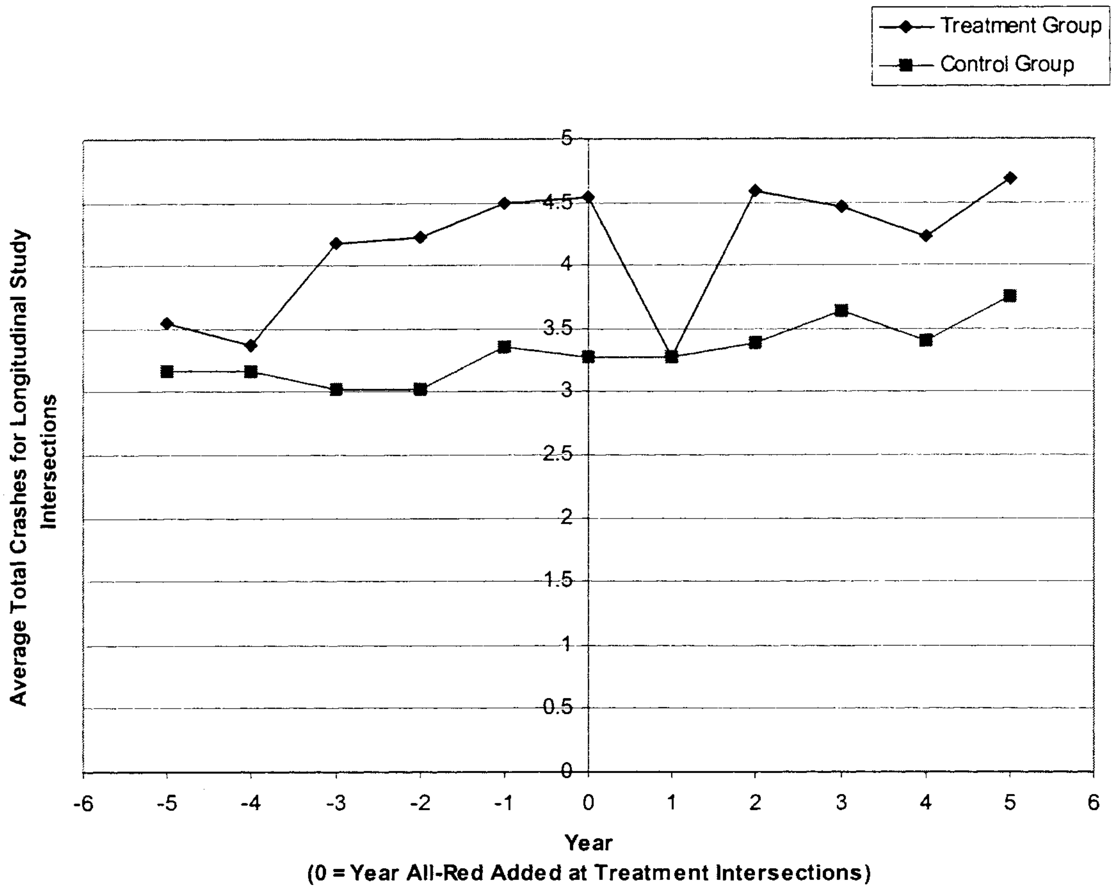


Figure 5.5: Average Total Crashes at Treatment and Control Group Intersections

Table 5.7: Descriptive Statistics for Total Crashes at Treatment and Control Group Intersections

	-5		-4		-3		-2	
	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl
Average	3.55	3.17	3.36	3.17	4.18	3.02	4.23	3.02
Minimum	0	0	0	0	0	0	0	0
Maximum	10	11	13	12	14	12	16	12
Median	3	2	3	2	3.5	2	3	2
Standard Deviation	2.65	2.82	2.89	2.83	3.35	2.75	3.50	2.88
Variance	7.02	7.93	8.34	8.01	11.20	7.59	12.28	8.28

	-1		0		1	
	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl
Average	4.50	3.36	4.55	3.28	3.27	3.28
Minimum	0	0	0	0	0	0
Maximum	13	15	11	15	10	17
Median	3	2	4	2	2	3
Standard Deviation	3.52	3.14	3.33	3.08	2.66	3.24
Variance	12.36	9.84	11.12	9.47	7.06	10.47

	2		3		4		5	
	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl
Average	4.59	3.38	4.45	3.64	4.23	3.40	4.68	3.74
Minimum	0	0	0	0	0	0	0	0
Maximum	11	14	15	15	11	15	17	24
Median	3.5	3	3.5	2	4	2	3.5	3
Standard Deviation	3.59	3.12	4.17	3.67	2.74	3.09	4.30	4.05
Variance	12.92	9.72	17.40	13.50	7.52	9.55	18.51	16.41

Trt: Treatment group intersections that received the all-red at year 0
Ctrl: Control group intersections that do not have the all-red

Table 5.8: Average Total Crashes at Treatment and Control Group Intersections

Time Period	Treatment Group	Control Group
-5 to -1	3.96	3.15
0	4.55	3.28
1 to 5	4.25	3.49

5.2.2. Relevant Crashes

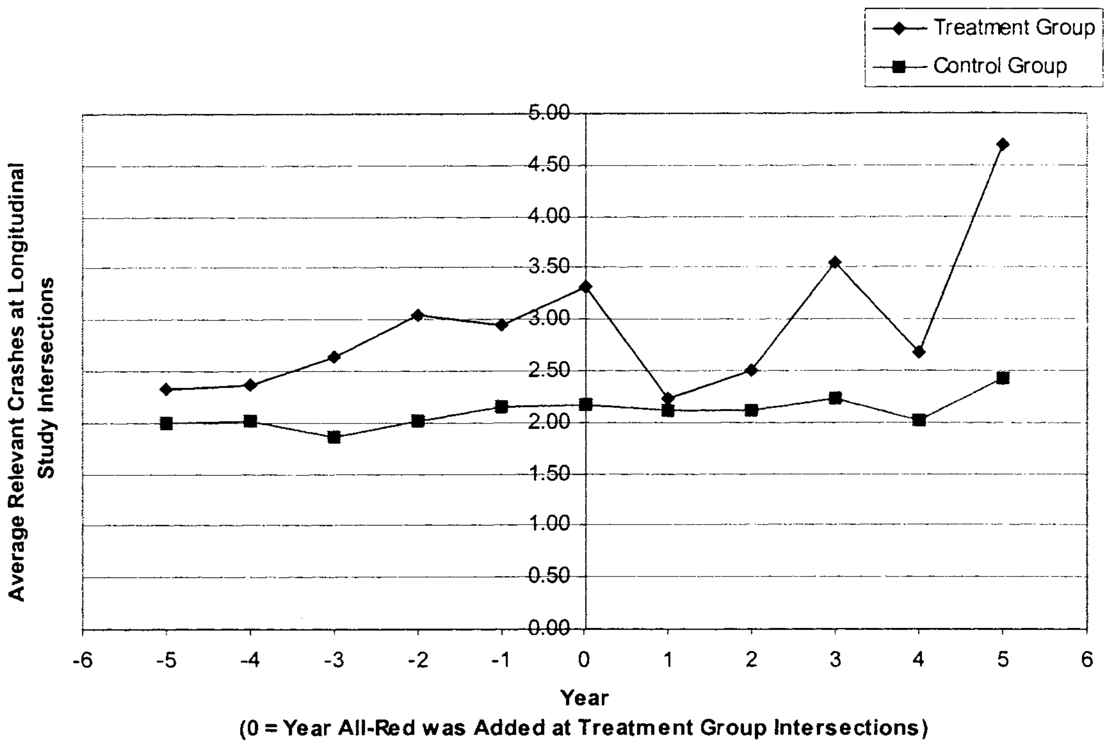


Figure 5.6: Average Relevant Crashes for Treatment and Control Group Intersections
Relevant Crashes: head on, rear end, right angle, left turn, right turn, and side swipe

Table 5.9: Descriptive Statistics for Relevant Crashes at Treatment and Control Group Intersections

Relevant Crashes: head on, rear end, right angle, left turn, right turn, and side swipe

	-5		-4		-3		-2	
	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl
Average	2.32	2.00	2.36	2.02	2.64	1.85	3.05	2.02
Minimum	0	0	0	0	0	0	0	0
Maximum	8	7	11	9	12	9	12	9
Median	2	2	2	1	2	1	2	2
Standard Deviation	1.99	1.85	2.44	2.08	3.05	2.14	2.84	2.10
Variance	3.94	3.43	5.96	4.33	9.29	4.56	8.05	4.41

	-1		0		1	
	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl
Average	2.95	2.15	3.32	2.17	2.23	2.11
Minimum	0	0	0	0	0	0
Maximum	9	12	9	13	9	11
Median	2.5	2	2	2	1	2
Standard Deviation	2.84	2.42	2.90	2.36	2.45	2.12
Variance	8.05	5.87	8.42	5.58	5.99	4.49

	2		3		4		5	
	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl
Average	2.50	2.11	3.55	2.23	2.68	2.02	4.68	2.43
Minimum	0	0	0	0	0	0	0	0
Maximum	8	13	12	13	8	9	17	21
Median	2	2	2	1	2	2	3.5	1
Standard Deviation	2.09	2.54	3.96	2.61	2.01	1.96	4.30	3.39
Variance	4.36	6.44	15.69	6.84	4.04	3.85	18.51	11.51

Trt: Treatment group intersections that received the all-red at year 0

Ctrl: Control group intersections that do not have the all-red

Relevant Crashes: head on, rear end, right angle, left turn, right turn, and side swipe

Table 5.10: Average Relevant Crashes for Treatment and Control Group Intersections

Relevant Crashes: head on, rear end, right angle, left turn, right turn, and side swipe

Time Period	Treatment Group	Control Group
-5 to -1	2.66	2.01
0	3.32	2.17
1 to 5	3.13	2.18

5.2.3. Total Crash Rate

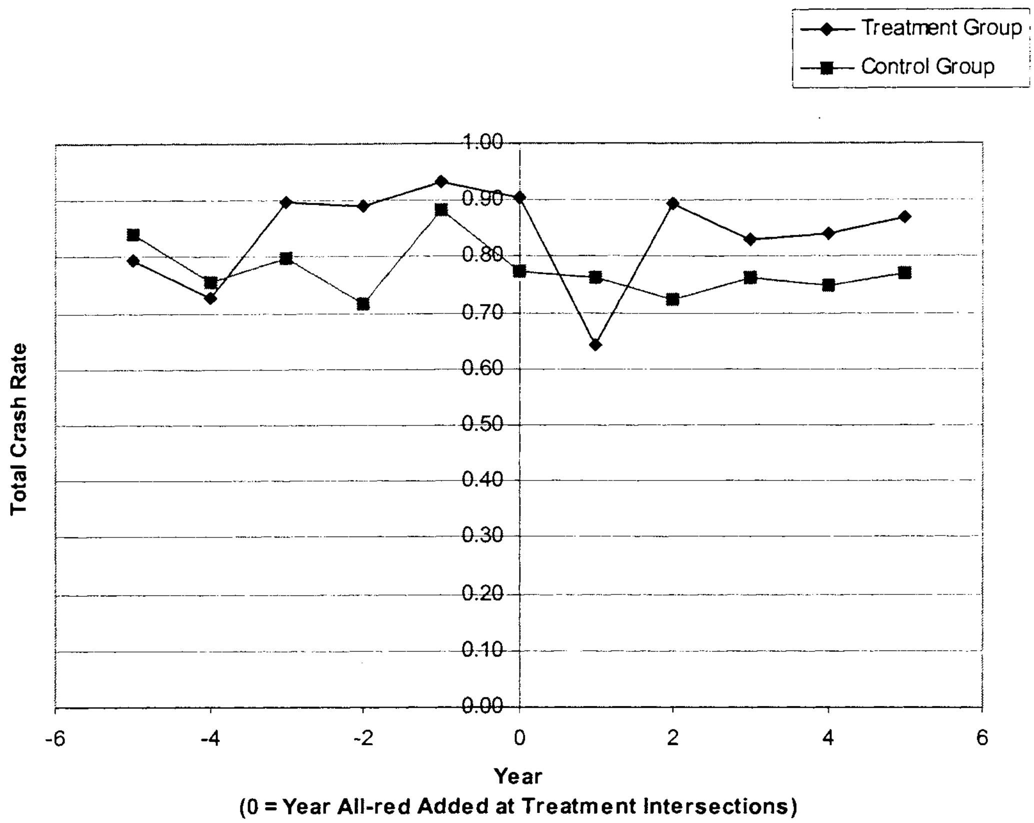


Figure 5.7: Average Total Crash Rates for Treatment and Control Group Intersections

Table 5.11: Descriptive Statistics for Total Crash Rates at Treatment and Control Group Intersections

	-5		-4		-3		-2	
	Trt	**Ctrl**	**Trt**	**Ctrl**	**Trt**	**Ctrl**	**Trt**	**Ctrl**
Average	0.794	0.841	0.727	0.756	0.897	0.798	0.890	0.716
Minimum	0	0	0	0	0	0	0	0
Maximum	2.122	3.076	1.892	2.042	2.091	2.974	3.009	2.512
Median	0.712	0.796	0.683	0.659	0.820	0.643	0.727	0.697
Standard Deviation	0.565	0.686	0.510	0.516	0.622	0.695	0.648	0.588
Variance	0.320	0.471	0.260	0.266	0.386	0.483	0.420	0.346

	-1		0		1	
	Trt	**Ctrl**	**Trt**	**Ctrl**	**Trt**	**Ctrl**
Average	0.932	0.885	0.905	0.773	0.643	0.763
Minimum	0	0	0	0	0	0
Maximum	2.182	3.321	2.066	4.571	1.918	3.853
Median	0.776	0.596	0.846	0.612	0.510	0.552
Standard Deviation	0.609	0.803	0.612	0.733	0.447	0.735
Variance	0.371	0.645	0.375	0.537	0.199	0.540

	2		3		4		5	
	Trt	**Ctrl**	**Trt**	**Ctrl**	**Trt**	**Ctrl**	**Trt**	**Ctrl**
Average	0.895	0.724	0.831	0.762	0.840	0.748	0.870	0.771
Minimum	0	0	0	0	0	0	0	0
Maximum	2.041	2.075	2.075	2.980	2.006	2.878	2.842	2.195
Median	0.858	0.724	0.657	0.534	0.701	0.717	0.636	0.670
Standard Deviation	0.629	0.501	0.691	0.652	0.544	0.633	0.706	0.578
Variance	0.396	0.251	0.478	0.426	0.296	0.400	0.498	0.334

Trt: Treatment group intersections that received the all-red at year 0
Ctrl: Control group intersections that do not have the all-red
Crash Rate: Per million Daily Entering Vehicles

Table 5.12: Average Total Crash Rates for Treatment and Control Group Intersections

Time Period	Treatment Group	Control Group
-5 to -1	0.56	0.80
0	0.65	0.77
1 to 5	0.58	0.75

5.2.4. Relevant Crash Rate

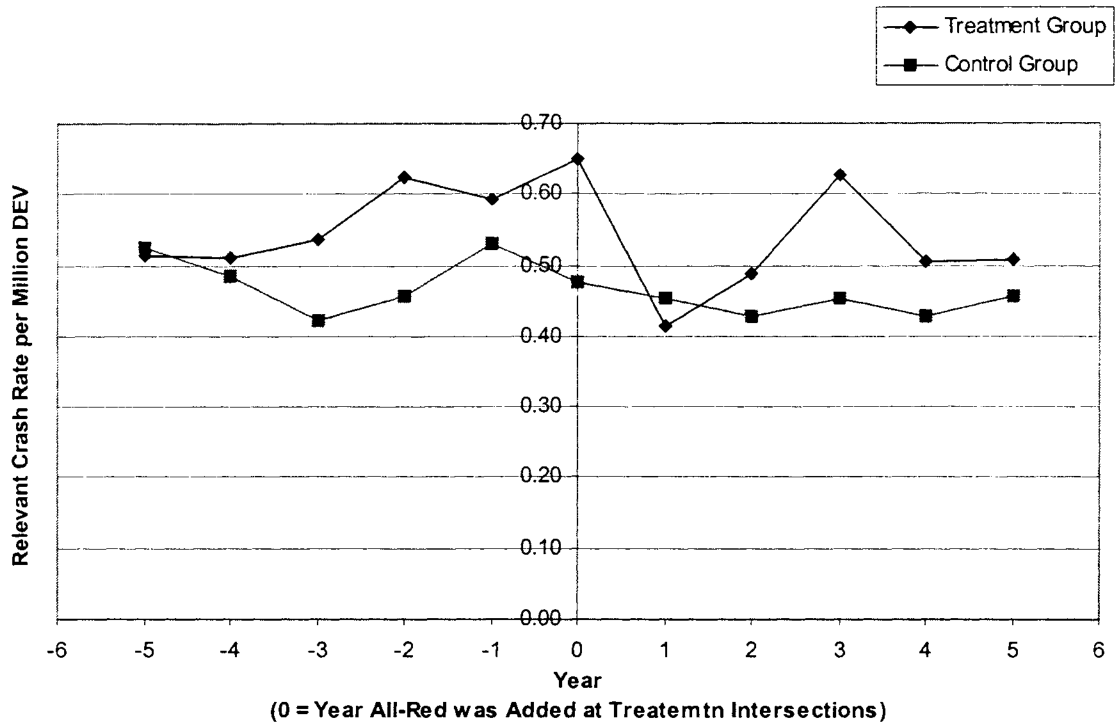


Figure 5.8: Average Relevant Crash Rates for Treatment and Control Group Intersections
Relevant Crashes: head on, rear end, right angle, left turn, right turn, and side swipe

Table 5.13: Descriptive Statistics for Relevant Crash Rates at Treatment and Control Group Intersections

	-5		-4		-3		-2	
	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl
Average	0.512	0.524	0.511	0.484	0.537	0.424	0.624	0.458
Minimum	0	0	0	0	0	0	0	0
Maximum	1.747	1.705	1.601	1.486	1.718	1.518	2.257	1.683
Median	0.474	0.465	0.441	0.361	0.363	0.322	0.485	0.403
Standard Deviation	0.414	0.469	0.443	0.416	0.543	0.431	0.538	0.402
Variance	0.171	0.220	0.196	0.173	0.295	0.185	0.290	0.162

	-1		0		1	
	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl
Average	0.592	0.531	0.650	0.477	0.413	0.454
Minimum	0	0	0	0	0	0
Maximum	1.617	2.055	1.691	2.612	1.726	1.955
Median	0.461	0.324	0.571	0.392	0.327	0.383
Standard Deviation	0.529	0.530	0.536	0.465	0.403	0.394
Variance	0.279	0.281	0.287	0.216	0.162	0.155

	2		3		4		5	
	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl	Trt	Ctrl
Average	0.487	0.427	0.625	0.454	0.505	0.428	0.506	0.456
Minimum	0	0	0	0	0	0	0	0
Maximum	1.509	1.927	2.020	2.235	1.459	1.290	1.501	1.921
Median	0.399	0.322	0.394	0.312	0.458	0.353	0.408	0.379
Standard Deviation	0.370	0.426	0.633	0.469	0.346	0.350	0.457	0.428
Variance	0.137	0.181	0.400	0.220	0.120	0.123	0.209	0.183

Trt: Treatment group intersections that received the all-red at year 0
Ctrl: Control group intersections that do not have the all-red
Relevant Crashes: head on, rear end, right angle, left turn, right turn, and side swipe
Crash Rate: Per million Daily Entering Vehicles

Table 5.14: Average Relevant Crash Rates for Treatment and Control Group Intersections

Time Period	Treatment Group	Control Group
-5 to -1	0.56	0.48
0	0.65	0.48
1 to 5	0.51	0.44

5.2.5. Before and After Study Conclusions

In the first year after the addition of the all-red clearance interval, there appears to be a decline in the total crashes, relevant crashes, total crash rate, and relevant crash rate. This concurs with other short-term before and after studies (less than a year) for installation of an all-red clearance interval which also report short-term safety benefits. After the first year, , number of crashes and crash rate return to the same levels or higher levels than before the addition of the all-red clearance interval. This phenomenon agrees with other long-term studies (more than a year) that did not report safety benefits of the all-red clearance interval (Roper, et. al, 1990).

In order to visualize the magnitude of the impact of the temporary decrease in the graphs after the addition of the all-red clearance interval, the control group relevant crash rate was graphed with a range of plus or minus one standard deviation of the relevant crash rate. In addition, three linear regressions were performed to obtain a rough estimate of the trends in relevant crash rates for the control group, the treatment group prior to the addition of the all-red, and the treatment group after the temporary drop from the addition of the all-red. All average crash rates fall within one standard deviation of the control group average, suggesting that the reduction in crash rates after the addition of the all-red clearance interval could be random. This graph allows estimation of the temporary safety benefit after the addition of the all-red clearance interval, approximately a 0.09 reduction in the crash rate for the first year. In the long-term the addition of the all-red clearance interval might reduce the rate at which the crash rate increase.

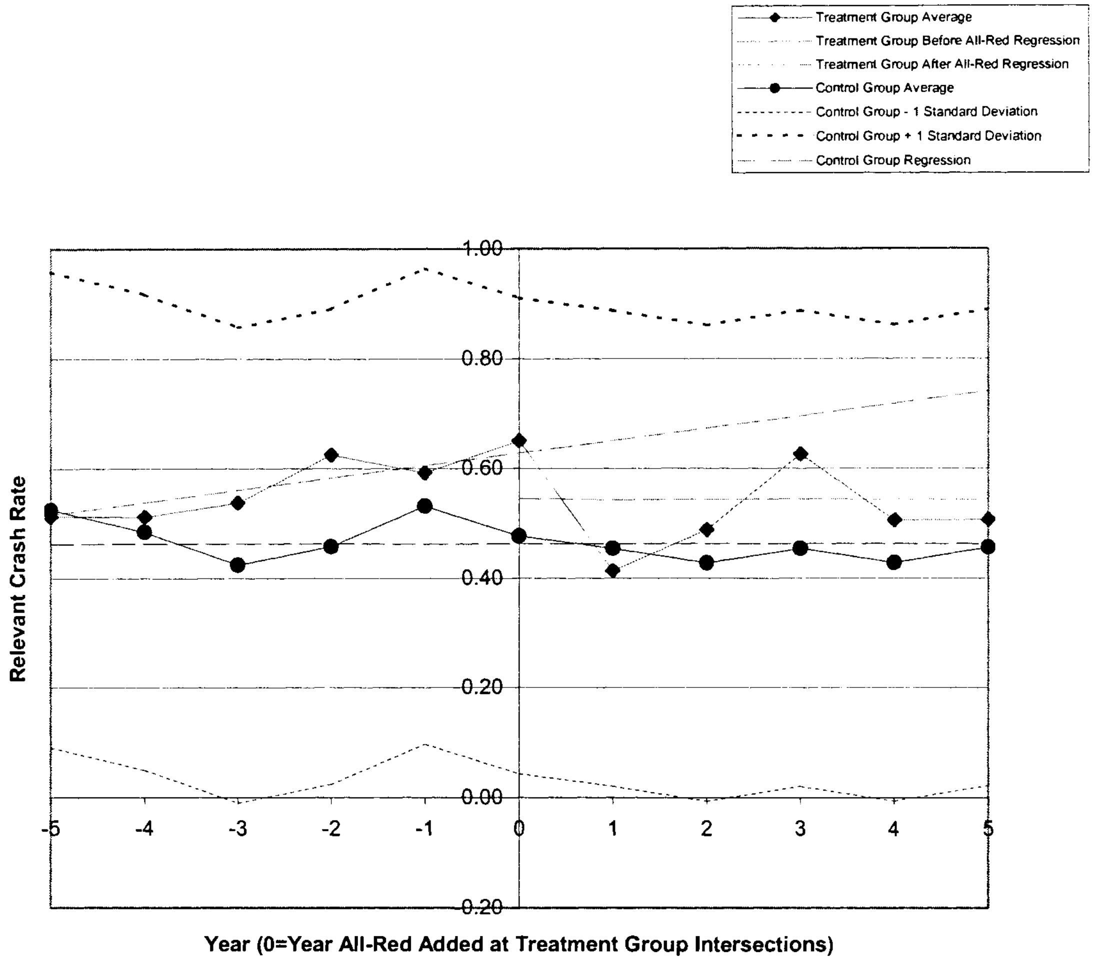


Figure 5.9: Relevant Crash Rates at Treatment and Control Group Intersections with Linear Regressions

Chapter 6: Models and Results

The previous section compared number of crashes and crash rates between intersections with and without an all-red interval. Without consideration of other variables that may affect intersection crashes, the average number of crashes and crash rates for intersection without an all-red interval were lower than those with the interval. In order to consider other variables which may contribute to differences in crashes, two different statistical models were developed. Using Statistical Analysis Software (SAS) version 9.0. Two different approaches were taken on the cross-section study data. The first approach used a generalized linear mixed model to determine if the all-red clearance interval affected relevant intersection crashes. The second used a linear mixed model.

6.1. Generalized Linear Mixed Model

In the cross-section study, crashes at intersections were measured repeatedly over time. In this case total crashes and relevant crashes were measured in 1999, 2000, 2001, and 2002 at the study intersections. Count data (crash counts) should not be modeled with a simple linear regression model. A simple linear regression model also assumes that all observations are independent. According an alternative modeling form was needed because there are four measurements at each intersection.

A generalized linear mixed model was proposed. This model accounts for "within-subject dependence" meaning that measurements on the same intersections are more similar than measurements on different intersections.

The following models employed a generalized linear mixed model with a Poisson error distribution model, and a link function of the natural logarithm. The response variable was the count data (relevant intersection crashes). Rather than using DEV as a covariate, all of the DEV values were centered on their mean. That is, the mean of all DEV values was subtracted from the DEV value to create a new variable cDEV. The generalized linear mixed model was run two different times, the first using an unstructured covariance structure and the second using a compound symmetric covariance structure.

The following steps were used in the analysis:

- All of the variables and their interactions were entered into the model. Equation 6.1. depicts the original generalized linear mixed model.

  Equation 6.1: Original Generalized Linear Mixed Model with all Variables and their Interactions

  $$\mathrm{IMP\_CR} \sim \mathrm{POISSON}\begin{bmatrix} \mathrm{TRT, D1, D2, INT\_LIGHTS, cDEV, TRT \times INT\_LIGHTS,} \\ \mathrm{TRT \times cDEV, D1 \times cDEV, D2 \times cDEV,} \\ \mathrm{INT\_LIGHTS \times cDEV} \end{bmatrix}$$

  Where:
  IMP_CR = Relevant Crashes
  TRT = Treatment (1 for All - red, 0 for No All - Red)
  D1 = Signal Visibility (1 for Overhead Both Directions, 0 for Otherwise)
  D2 = Signal Visibility (1 for Overhead One Direction, 0 for Otherwise)
  INT_LIGHTS = Presence of Lighting at the Intersection (1 for Yes, 0 for No)
  cDEV = Centered DEV

- Because this was an observational study, when main effects and interactions were not significant at a reasonable significance level (α=0.05), they were dropped from the model.

- All main effects, intersection characteristics that were significant, were entered into the model, and are shown in Equation 6.2.

Equation 6.2: Reduced Generalized Linear Mixed Model

$$\begin{aligned}
&\text{IMP_CR} \sim \text{POISSON}\left[\text{TRT, D2, cDEV}\right]\\
&\text{Where:}\\
&\text{IMP_CR} = \text{Relevant Crashes}\\
&\text{TRT} = \text{Treatment (1 for All - red, 0 for No All - Red)}\\
&\text{D2} = \text{Signal Visibility (1 for Overhead One Direction, 0 for Otherwise)}\\
&\text{cDEV} = \text{Centered DEV}
\end{aligned}$$

- Since the generalized linear mixed model was compared to a linear mixed model in the next section, the models were determined with the same variables. Since this was the case, the variable for the presence of lighting at the intersection and the interaction between treatment and centered DEV were added back into the model one at a time. The final model is shown in Equation 6.3.

Equation 6.3: Final Generalized Linear Mixed Model

$$\begin{aligned}
&\text{IMP_CR} \sim \text{POISSON}\begin{bmatrix}\text{TRT, D2, INT_LIGHTS, cDEV,}\\ \text{TRT} \times \text{cDEV}\end{bmatrix}\\
&\text{Where:}\\
&\text{IMP_CR} = \text{Relevant Crashes}\\
&\text{TRT} = \text{Treatment (1 for All - red, 0 for No All - Red)}\\
&\text{D2} = \text{Signal Visibility (1 for Overhead One Direction, 0 for Otherwise)}\\
&\text{INT_LIGHTS} = \text{Presence of Lighting at the Intersection (1 for Yes, 0 for No)}\\
&\text{cDEV} = \text{Centered DEV}
\end{aligned}$$

- Finally, two generalized linear mixed models were created: one with an unstructured covariance structure and one with a compound symmetric covariance structure. The definitions of these covariance structures follow.

6.1.1. Generalized Linear Mixed Model with an Unstructured Covariance Structure

An unstructured covariance structure was used between the time points within a subject (here an intersection). This type of covariance matrix is a completely general (unstructured) covariance matrix using only variance and covariance parameters, and is depicted in Table 6.1. In this structure, all variances are nonnegative and covariances can be either negative or positive. An unstructured covariance structure allowed variances of crashes at each intersection to be different for each year. This covariance structure also implies that the covariance and correlations of crashes at an intersection can differ depending on which two years are being considered. The unstructured covariance parameter estimates for the generalized linear mixed model for the cross-section study is shown in Table 6.2. Each row and column in the 4x4 matrix stands for an analysis year (1999, 2000, 2001, and 2002). In the unstructured covariance matrix, Table 6.2, the elements along the rows, from the diagonal outwards are decreasing. This is because from 1999 to 2000 there is a higher correlation in a particular intersection than there is from 1999 to 2002.

Table 6.1: Unstructured Covariance Structure

	1999	2000	2001	2001
1999	σ_1^2	σ_{21}	σ_{31}	σ_{41}
2000	σ_{21}	σ_2^2	σ_{32}	σ_{42}
2001	σ_{31}	σ_{32}	σ_3^2	σ_{43}
2002	σ_{41}	σ_{42}	σ_{43}	σ_4^2

Table 6.2: Unstructured Covariance Structure for the Generalized Linear Mixed Model

$$\begin{bmatrix} 2.13 & 1.10 & 1.02 & 0.76 \\ 1.10 & 1.53 & 0.72 & 0.57 \\ 1.02 & 0.72 & 1.73 & 0.74 \\ 0.76 & 0.57 & 0.74 & 1.43 \end{bmatrix}$$

Table 6.3 shows the solution vector for the fixed effects. Equation 6.4 gives the expected number of relevant crashes. If the value of X_1, X_2, X_3, or X_1xX_4 is 1, it does not affect the number of expected intersection crashes. If the value is 0, the variable will have the following effects: a negative regression coefficient means that the variable causes a reduction in expected intersection crashes and a positive regression coefficient means that the variable causes an increase in expected intersection crashes. In this model, the safest intersection (intersection with the least expected crashes) would have the following characteristics: no all-red clearance interval (X_1 = 0), overhead signals in all directions or neither direction (X_2=0), and no intersection lighting (X_3=0). All SAS results for the generalized linear mixed model with the unstructured covariance structure are located in Appendix B.

If there is an intersection that has an all-red clearance interval (X_1=1), overhead signals in one direction (X_2=1), has intersection lighting (X_3=1), and the DEV is one more than the average DEV (X_4=1), the expected number of crashes at that intersection would be 2.3275 per year. If an intersection has all of the same parameters as the previous example, but operates without an all-red clearance interval (X_1=0), the expected number of intersection crashes is 1.455 per year.

Table 6.3: Solution Vector for Fixed Effects of the Generalized Linear Mixed Model with an Unstructured Covariance Structure

Effect	X_1	X_2	X_3	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept				0.8447	0.1481	72	5.70	< 0.0001
X_1	0			− 0.4700	0.1592	72	− 2.95	0.0043
X_1	1			0	.	.	.	.
X_2		0		0.3874	0.1482	72	2.61	0.0109
X_2		1		0	.	.	.	.
X_3			0	− 0.3477	0.2841	72	− 1.22	0.2251
X_3			1	0	.	.	.	.
X_4				0.000094	0.000012	72	7.93	< 0.0001
$X_1 \times X_4$	0			-6.58×10^{-6}	0.000019	72	− 0.35	0.7301
$X_1 \times X_4$	1			0	.	.	.	.

Where :
X_1 = Treatment (1 = All - Red, 0 = No All - Red)
X_2 = Signal Visibility (1 = Overhead Signals One Direction, 0 = Otherwise)
X_3 = Presence of Street Lights at the Intersecti on (1 = Yes, 0 = No)
X_4 = Centered DEV

Equation 6.4: Expected Number of Relevant Crashes Using the Generalized Linear Mixed Model with an Unstructured Covariance Structure

$$\text{Expected Number of Relevant Crashes} = e^{\left(\begin{array}{l}0.8447-0.4700(1-X_1)+0.3847(1-X_2)\\ -0.3447(1-X_3)+0.000094\times X_4\\ -6.58\times10^{-6}\times X_4(1-X_1)\end{array}\right)}$$

Where:

X_1 = Treatment (1 = All - Red, 0 = No All - Red)

X_2 = Signal Visibility (1 = Overhead Signals One Direction, 0 = Otherwise)

X_3 = Presence of Street Lights at the Intersection (1 = Yes, 0 = No)

X_4 = Centered DEV

6.1.2. Generalized Linear Mixed Model with a Compound Symmetric Covariance Structure

After the unstructured covariance structure was explored, a compound symmetric covariance structure was employed in the generalized linear mixed model. These two different covariance structures were explored to determine which one produced a better-fit model. A compound symmetric covariance structure has constant variance and constant covariance. This means that the variance of crashes at an intersection is the same for all four years. This covariance structure also implies that covariance and correlation between any two years is the same. The compound symmetric covariance structure is depicted in Table 6.3. The compound symmetric covariance structure for the generalized linear mixed model is in Table 6.4.

Table 6.4: Compound Symmetric Covariance Structure

$$\begin{array}{c|cccc} & 1999 & 2000 & 2001 & 2002 \\ 1999 & \sigma^2+\sigma_1 & \sigma_1 & \sigma_1 & \sigma_1 \\ 2000 & \sigma_1 & \sigma^2+\sigma_1 & \sigma_1 & \sigma_1 \\ 2001 & \sigma_1 & \sigma_1 & \sigma^2+\sigma_1 & \sigma_1 \\ 2002 & \sigma_1 & \sigma_1 & \sigma_1 & \sigma^2+\sigma_1 \end{array}$$

Table 6.5: Compound Symmetric Covariance Structure for the Generalized Linear Mixed Model

$$\begin{bmatrix} 1.69 & 0.79 & .79 & 0.79 \\ 0.79 & 1.69 & 0.79 & 0.79 \\ 0.79 & 0.79 & 1.69 & 0.79 \\ 0.79 & 0.79 & 0.79 & 1.69 \end{bmatrix}$$

Table 6.6 shows the solution vector for the fixed effects of the generalized linear mixed model with a compound symmetric covariance structure. Equation 6.5 gives the expected number of relevant crashes. If the value of X_1, X_2, X_3, or X_1xX_4 is 1, it does not affect the number of expected intersection crashes. If the value is 0, the variable will have the following effects: a negative regression coefficient means that the variable causes a reduction in expected intersection crashes and a positive regression coefficient means that the variable causes an increase in expected intersection crashes. In this model, the safest intersection (intersection with the least expected crashes) would have the following characteristics: no all-red clearance interval ($X_1 = 0$), overhead signals in all directions or neither direction ($X_2=0$), and no intersection lighting (X_3=0). All SAS results for the generalized linear mixed model with the compound symmetric covariance structure are located in Appendix B.

For an intersection that has an all-red clearance interval (X_1=1), overhead signals in one direction (X_2=1), has intersection lighting (X_3=1), and the DEV is one more than the average DEV (X_4=1), the expected number of crashes at that intersection would be 2.1800 per year. If an intersection has all of the same parameters as the previous example, but operates without an all-red clearance interval (X_1=0), the expected number of intersection crashes is 1.4300 per year.

Table 6.6: Solution Vector for Fixed Effects of the Generalized Linear Mixed Model with a Compound Symmetric Covariance Structure

Effect	X_1	X_2	X_3	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept				0.7793	0.1554	72	5.01	< 0.0001
X_1	0			−0.4206	0.1642	72	−2.56	0.0125
X_1	1			0	.	.	.	.
X_2		0		0.4392	0.1545	72	2.84	0.0058
X_2		1		0	.	.	.	.
X_3			0	−0.3250	0.2900	72	−1.12	0.2661
X_3			1	0	.	.	.	.
X_4				0.000100	0.000012	226	8.11	< 0.0001
$X_1 \times X_2$	0			-8.54×10^{-6}	0.000020	226	−0.44	0.6622
$X_1 \times X_2$	1			0	.	.	.	.

Where:

X_1 = Treatment (1 = All-Red, 0 = No All-Red)

X_2 = Signal Visibility (1 = Overhead Signals One Direction, 0 = Otherwise)

X_3 = Presence of Street Lights at the Intersection (1 = Yes, 0 = No)

X_4 = Centered DEV

Equation 6.5: Expected Number of Relevant Crashes Using the Generalized Linear Mixed Model with a Compound Symmetric Covariance Structure

$$\text{Expected Number of Relevant Crashes} = e^{\begin{pmatrix} 0.7793\text{-}0.4206(1\text{-}X_1)+0.4392(1\text{-}X_2) \\ \text{-}0.3250(1\text{-}X_3)+0.000100\times X_4 \\ -8.54\times10^{-6}\times X_4(1-X_1) \end{pmatrix}}$$

Where :

X_1 = Treatment (1 = All - Red, 0 = No All - Red)

X_2 = Signal Visibility (1 = Overhead Signals One Direction, 0 = Otherwise)

X_3 = Presence of Street Lights at the Intersection (1 = Yes, 0 = No)

X_4 = Centered DEV

6.1.3. Advantages and Disadvantages of the Generalized Linear Mixed Model

There are some advantages of using a generalized linear mixed model with a Poisson error distribution model and the link function being the natural logarithm. These advantages include: using a generalized linear model with random effects to model the situation and offering a more correct way of approaching the situation because this study is dealing with count data that is not normally distributed. A disadvantage of the previous models is that they use cumbersome nonlinear equations to complete the analysis.

6.2. Linear Mixed Model

Sometimes it is easier to use a standard normal analysis such as a mixed linear model instead of using a more complicated analysis such as the generalized mixed linear model. One of the three primary assumptions of a mixed linear model is that the data are normally distributed. Relevant crash histograms were created using the log of crashes, square root of crashes, and cubic root of crashes at the study intersections over the four-year study period. The square root of crashes produced a normally distributed histogram, and is shown in Figure 6.1. Since the square root transformation produced data that were nearly normally distributed, a normal linear mixed model was fitted to the square root crash data.

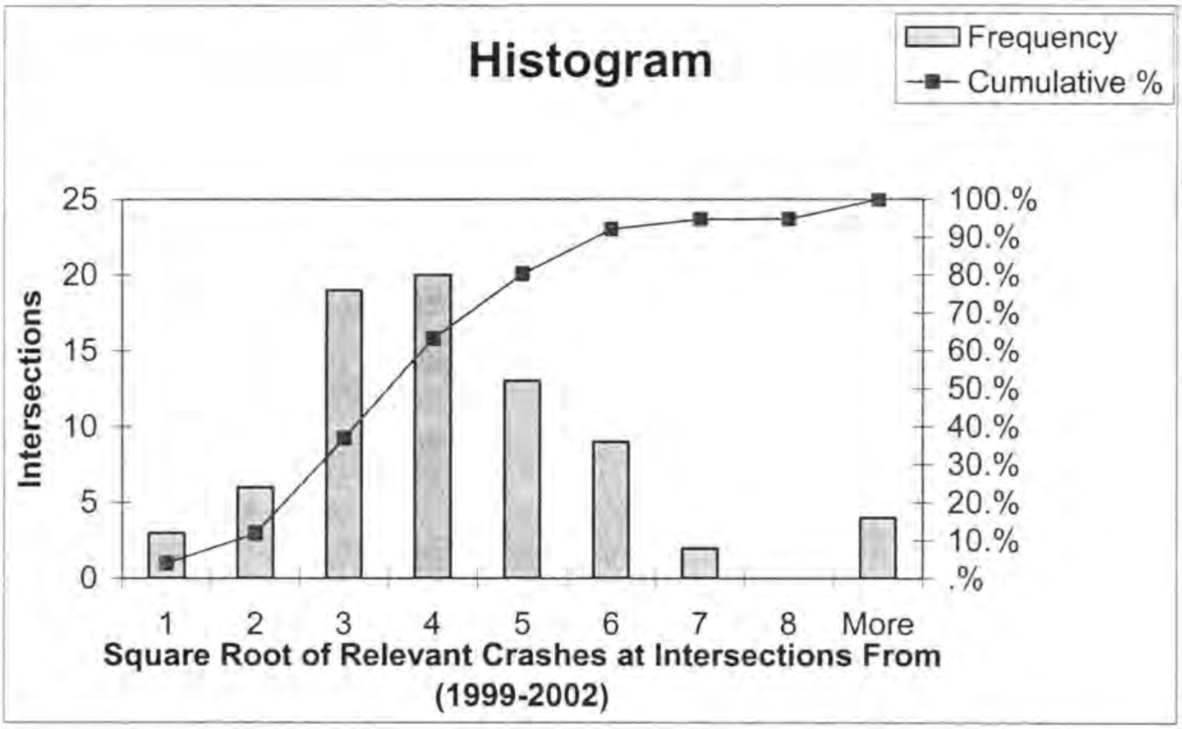


Figure 6.1: Square Root Transformation of the Data

Once the proper transformation of the data was obtained, a linear mixed model was utilized to model the data. As in the previous models, the response variable was the count data, relevant intersection crashes. Rather than using DEV, all of the DEV values were centered on their mean. The linear mixed model was also run two different times, the first using an unstructured covariance structure and the second using a compound symmetric covariance structure.

The following steps were used in the analysis:

- All of the variables and their interactions were entered into the model. Equation 6.6 depicts the original linear mixed model.

Equation 6.6: Original Linear Mixed Model with all Variables and their Interactions

$$\text{Square Root (IMP\_CR)} \sim \text{Normal}\begin{bmatrix} \mu(\text{TRT}, \text{D1}, \text{D2}, \text{INT\_LIGHTS}, \text{cDEV}, \\ \text{TRT} \times \text{INT\_LIGHTS}, \\ \text{TRT} \times \text{cDEV}, \text{D1} \times \text{cDEV}, \text{D2} \times \text{cDEV}, \\ \text{INT\_LIGHTS} \times \text{cDEV}), \sigma \end{bmatrix}$$

Where:
IMP_CR = Relevant Crashes
TRT = Treatment (1 for All - red, 0 for No All - Red)
D1 = Signal Visibility (1 for Overhead Both Directions, 0 for Otherwise)
D2 = Signal Visibility (1 for Overhead One Direction, 0 for Otherwise)
INT_LIGHTS = Presence of Lighting at the Intersection (1 for Yes, 0 for No)
cDEV = Centered DEV

- Because this was an observational study, when interactions were not significant at a reasonable significance level, they were dropped from the model.
- All main effects were entered into the model, and are shown in Equation 6.7.

▪

Equation 6.7. Reduced Linear Mixed Model

$$\text{Square Root (IMP\_CR)} \sim \text{Normal}\left[\mu(\text{TRT, D2, INT\_LIGHTS, cDEV, CDEV} \times \text{TRT}), \sigma\right]$$

Where:

IMP_CR = Relevant Crashes

TRT = Treatment (1 for All-red, 0 for No All-Red)

D2 = Signal Visibility (1 for Overhead One Direction, 0 for Otherwise)

INT_LIGHTS = Presence of Lighting at the Intersection (1 for Yes, 0 for No)

cDEV = Centered DEV

- Finally, two linear mixed models were created: one with an unstructured covariance structure and one with a compound symmetric covariance structure.

6.2.1. Linear Mixed Model with an Unstructured Covariance Structure

Just as for the generalized linear mixed model, an unstructured covariance structure was used for the linear mixed model. The unstructured covariance structure is located in Table 6.7, and Table 6.8 shows the solution vector for fixed effects of the linear mixed model with an unstructured covariance structure. Equation 6.8 gives the expected number of relevant crashes. If the value of X_1, X_2, X_3, or $X_1 x X_4$ is 1, it does not affect the number of expected intersection crashes. If the value is 0, the variable will have the following effects: a negative regression coefficient means that the variable causes a reduction in expected intersection crashes and a positive regression coefficient means that the variable causes an increase in expected intersection crashes. In this model, the safest intersection (intersection with the least expected crashes) would have the following characteristics: no all-red clearance interval ($X_1 = 0$), overhead signals in all directions or neither direction (X_2=0), and no intersection lighting (X_3=0). All SAS results for the linear mixed model with the unstructured covariance structure are located in Appendix B.

In order to determine the expected number of crashes, the estimated expected number of crashes in the transformed scale (in our case, square root scale) needs to be transformed back to the original scale. In this case, just squaring the square root of estimated expected crashes is not correct because the bias correction needs to be applied. The back transformation for the expected number of crashes is shown in the second portion of Equation 6.8. This correction can be derived using a Taylor expansion of the non-linear function on expected crashes that results from the power transformation. The term that is added to the naïve back-transformation is one half of the second derivative of the inverse transformation with respect to $\hat{X}$ (the expected number of intersection crashes in the transformed scale) times the within intersection variance. Since an unstructured covariance structure was used in this model, the within intersection variance was approximated for each year. For 1999, the within intersection variance is 0.3993. (From Table 6.7. 0.3993 = 0.6712 – (0.2917 + 0.2801 + 0.2440)/3.)

If there is an intersection that has an all-red clearance interval (X_1=1), overhead signals in one direction (X_2=1), has intersection lighting (X_3=1), and the DEV is one more than the average DEV (X_4=1), the expected number of crashes at that intersection would be 2.24 per year. If an intersection has all of the same parameters as the previous example, but operates without an all-red clearance interval (X_1=0), the expected number of intersection crashes is 1.50 per year.

Table 6.7: Unstructured Covariance Structure for the Linear Mixed Model. (Data are the square root of crashes.)

$$\begin{bmatrix} 0.67 & 0.29 & 0.28 & 0.24 \\ 0.29 & 0.52 & 0.20 & 0.15 \\ 0.28 & 0.20 & 0.52 & 0.20 \\ 0.24 & 0.15 & 0.20 & 1.43 \end{bmatrix}$$

Table 6.8: Solution Vector for Fixed Effects of the Linear Mixed Model with an Unstructured Covariance Structure

Effect	X_1	X_2	X_3	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept				1.3584	0.1252	72	10.85	< 0.0001
X_1	0			-0.3083	0.1273	72	-2.42	0.0180
X_1	1			0	.	.	.	.
X_2		0		0.3727	0.1340	72	2.78	0.0069
X_2		1		0	.	.	.	.
X_3			0	-0.5276	0.2309	72	−2.29	0.0252
X_3			1	0	.	.	.	.
X_4				0.000113	0.000014	72	7.90	< 0.0001
$X_1 \times X_2$	0			-0.00004	0.000020	72	−2.19	0.0317
$X_1 \times X_2$	1			0	.	.	.	.

Where:

X_1 = Treatment (1 = All-Red, 0 = No All-Red)

X_2 = Signal Visibility (1 = Overhead Signals One Direction, 0 = Otherwise)

X_3 = Presence of Street Lights at the Intersection (1 = Yes, 0 = No)

X_4 = Centered DEV

Equation 6.8: Expected Number of Relevant Crashes Using the Linear Mixed Model with an Unstructured Covariance Structure

$$\sqrt{\text{Expected Number of Relevant Crashes}} = \begin{pmatrix} 1.3584 - 0.3083(1 - X_1) + 0.3727(1 - X_2) \\ -0.5276(1 - X_3) + 0.000113 \times X_4 \\ -0.00004 \times X_4(1 - X_1) \end{pmatrix}$$

$$\text{Expected Number of Relevant Crashes} = \sqrt{\text{Expected Number of Relevant Crashes}} + \frac{1}{2} \times 2 \times \sigma^2_{\text{within}}$$

Where:

X_1 = Treatment (1 = All-Red, 0 = No All-Red)

X_2 = Signal Visibility (1 = Overhead Signals One Direction, 0 = Otherwise)

X_3 = Presence of Street Lights at the Intersection (1 = Yes, 0 = No)

X_4 = Centered DEV

6.2.2. Linear Mixed Model with a Compound Symmetric Covariance Structure

Just as for the generalized linear mixed model, a compound symmetric covariance structure was used for the linear mixed model. The compound symmetric covariance structure is located in Table 6.9, and Table 6.10 shows the solution vector for fixed effects of the linear mixed model with a compound symmetric covariance structure. If the value of X_1, X_2, X_3, or X_1xX_4 is 1, it does not affect the number of expected intersection crashes. If the value is 0, the variable will have the following effects: a negative regression coefficient means that the variable causes a reduction in expected intersection crashes and a positive regression coefficient means that the variable causes an increase in expected intersection crashes. In this model, the safest intersection (intersection with the least expected crashes) would have the following characteristics: no all-red clearance interval (X_1 = 0), overhead signals in all directions or neither direction (X_2=0), and no intersection lighting (X_3=0). All

SAS results for the linear mixed model with the compound symmetric covariance structure are located in Appendix B.

In order to determine the expected number of crashes, the estimated expected number of crashes in the transformed scale (in our case, square root scale) needs to be transformed back to the original scale. In this case, just squaring the square root of estimated expected crashes is not correct because the bias correction needs to be applied. The back transformation for the expected number of crashes is shown in the second portion of Equation 6.8. This correction can be derived using a Taylor expansion of the non-linear function on expected crashes that results from the power transformation. The term that is added to the naïve back-transformation is one half of the second derivative of the inverse transformation with respect to $\hat{X}$ (the expected number of intersection crashes in the transformed scale) times the within intersection variance. In this model the within intersection variance is 0.3281. (From Table 6.9. 0.3281 = 0.5559 - 0.2279.)

If there is an intersection that has an all-red clearance interval (X_1=1), overhead signals in one direction (X_2=1), has intersection lighting (X_3=1), and the DEV is one more than the average DEV (X_4=1), the expected number of crashes at that intersection would be 2.07 per year. If an intersection has all of the same parameters as the previous example, but operates without an all-red clearance interval (X_1=0), the expected number of intersection crashes is 1.41 per year.

Table 6.9: Compound Symmetric Covariance Structure for the Linear Mixed Model (Data are the square root of crashes.)

$$\begin{bmatrix} 0.56 & 0.23 & 0.23 & 0.23 \\ 0.23 & 0.56 & 0.23 & 0.23 \\ 0.23 & 0.23 & 0.56 & 0.20 \\ 0.23 & 0.23 & 0.23 & 0.56 \end{bmatrix}$$

Table 6.10: Solution Vector for Fixed Effects of the Linear Mixed Model with a Compound Symmetric Covariance Structure

Effect	X_1	X_2	X_3	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept				1.3192	0.1286	72	10.26	< 0.0001
X_1	0			-0.2784	0.1310	72	-2.13	0.0370
X_1	1			0	.	.	.	.
X_2		0		0.3958	0.1379	72	2.87	0.0054
X_2		1		0	.	.	.	.
X_3			0	−0.5157	0.2377	72	−2.17	0.0333
X_3			1	0	.	.	.	.
X_4				0.000119	0.000015	226	7.98	< 0.0001
$X_1 \times X_2$	0			−0.00005	0.000021	226	−2.26	0.0248
$X_1 \times X_2$	1			0	.	.	.	.

Where:

X_1 = Treatment (1 = All - Red, 0 = No All - Red)

X_2 = Signal Visibility (1 = Overhead Signals One Direction, 0 = Otherwise)

X_3 = Presence of Street Lights at the Intersection (1 = Yes, 0 = No)

X_4 = Centered DEV

Equation 6.9: Expected Number of Relevant Crashes Using the Linear Mixed Model with a Compound Symmetric Covariance Structure

$$\sqrt{\text{Expected Number of Relevant Crashes}} = \begin{pmatrix} 1.3192 - 0.2784(1 - X_1) + 0.3958(1 - X_2) \\ - 0.5157(1 - X_3) + 0.000119 \times X_4 \\ - 0.00005 \times X_4(1 - X_1) \end{pmatrix}$$

$$\text{Expected Number of Relevant Crashes} = \sqrt{\text{Expected Number of Relevant Crashes}} + \frac{1}{2} \times 2 \times \sigma^2_{\text{within}}$$

Where:

X_1 = Treatment (1 = All-Red, 0 = No All-Red)

X_2 = Signal Visibility (1 = Overhead Signals One Direction, 0 = Otherwise)

X_3 = Presence of Street Lights at the Intersection (1 = Yes, 0 = No)

X_4 = Centered DEV

6.2.3. Advantages and Disadvantages of the Linear Mixed Model

Parameters in the normal linear mixed model can be estimated by solving a set of linear equations, once the variance components have been obtained. Thus, computations are less intensive (and results are more stable) than in the case of the generalized linear mixed model, in general. In this study, relatively smaller standard errors associated to the regression coefficient resulted in a larger set of statistically significant effect on crashes. In addition, when possible, it is always to use a linear model because it is easier to understand and interpret.

6.3. Model Summary

All four models had relatively similar solution vectors meaning the estimates for the different effects were all in the same direction and similar in magnitude. The major difference between the generalized linear mixed models and the linear mixed models is that both generalized linear mixed models did not find the effects of the presence of street lighting and the interaction of treatment and centered DEV to be significant. Although these effects were not significant, they were kept in the models in order to compare the models to the linear mixed models. Out of the four models investigated, the linear mixed model with a compound symmetric covariance structure ended up being the best model because it had the smallest Akaike's Information Criterion (AIC) and Schwarz's Bayesian Criterion (BIC) values, as shown in Table 6.11. Table 6.12 shows the predicted number of intersection crashes using the different models. The typical intersection refers to the typical intersection with and without the all-red clearance interval. The typical intersection characteristics are presented in Table 6.13. The average of intersections refers to the average predicted values for all intersections with and without the all-red clearance interval.

Table 6.11: Summary of Fit Statistics

Model	-2 Res Log Likelihood	AIC (Smaller is Better)	AICC (Smaller is Better)	BIC (Smaller is Better)
Generalized Linear Mixed Model with an Unstructured Covariance Structure	724.2	744.2	745.0	767.5
Generalized Linear Mixed Model with a Compound Symmetric Covariance Structure	735.3	739.3	739.3	744.0
Mixed Linear Model with an Unstructured Covariance Structure	663.4	683.4	684.1	706.7
Mixed Linear Model with a Compound Symmetric Covariance Structure	669.0	673.0	673.0	677.7

Table 6.12: Predicted Number of Intersection Crashes Using Models

	Typical Intersection			Average of Intersections		
	All-red	No all-red	Diff.	All-red	No all-red	Diff.
GLMM (UN)	3.33	1.58	**1.75**	3.99	2.04	**1.95**
GLMM (CS)	3.27	1.60	**1.67**	4.00	2.07	**1.93**
LMM (UN)	3.36	1.67	**1.69**	3.77	1.92	**1.85**
LMM (CS)	3.24	1.63	**1.61**	3.78	1.92	**1.86**
SLR	4.02	2.09	**1.93**	4.02	2.09	**1.93**
Actual	na	na	na	4.02	2.09	**1.93**

Table 6.13: Typical Intersection Characteristics

	Typical Intersection	
	All-Red	No All-Red
X1	1	0
X2	0.342	0.368
X3	0.921	0.895
X4	1413	-1413
X1*X4	1413	0

Chapter 7: Cost of Implementation

Generally, a benefit cost analysis would be appropriate. In this case, a benefit cost analysis could not be performed because the statistical analysis did not show a benefit of using an all-red clearance interval. However, as engineers continue to specify all-red clearance intervals in the belief of safety benefits. Following are some estimates of system wide costs incurred by the city of Minneapolis if the all-red clearance interval is to be implemented at remaining signalized intersections. The following assumptions were made:

- Cycle length of 60 seconds with 2 phases
- Base saturation flow rate is 1900 passenger cars per hour per lane (pcphpl)
- Effective green time per cycle is 54 seconds without the all-red clearance interval
- Effective green time per cycle is 50 seconds with the all-red clearance interval (assumes two – all-red clearance intervals of 2 seconds each)
- Peak Hour Volume is 1450 pcphpl
- Peak factors for four consecutive fifteen minute intervals are:
    - 0.20
    - 0.35
    - 0.30
    - 0.15
- Peak fifteen minute flow rates were calculated using the peak fifteen minute factors
- There are two peak hours per workday
- There are 250 workdays per year
- Value of travel time is $15 per vehicle per hour

- 803 total intersections in Minneapolis
    - 699 intersections with the all-red clearance interval
    - 104 intersections without the all-red clearance interval

An analysis was performed at one-minute intervals using the previous assumptions for an intersection with the all-red clearance interval and an intersection without the all-red clearance interval. Figure 8.1 depicts cumulative arrivals and departures versus time for an intersection with and without the all-red clearance interval during peak hour traffic. In this scenario, the intersection with the all-red clearance interval experiences 77% more delay during peak hour traffic than the intersection without the all-red clearance interval. Assuming two peak hour traffic periods per workday, 250 workdays per year, and $15 per vehicle hour, the cost to users during peak hour is $204,000 more per year if there is an all-red clearance interval.

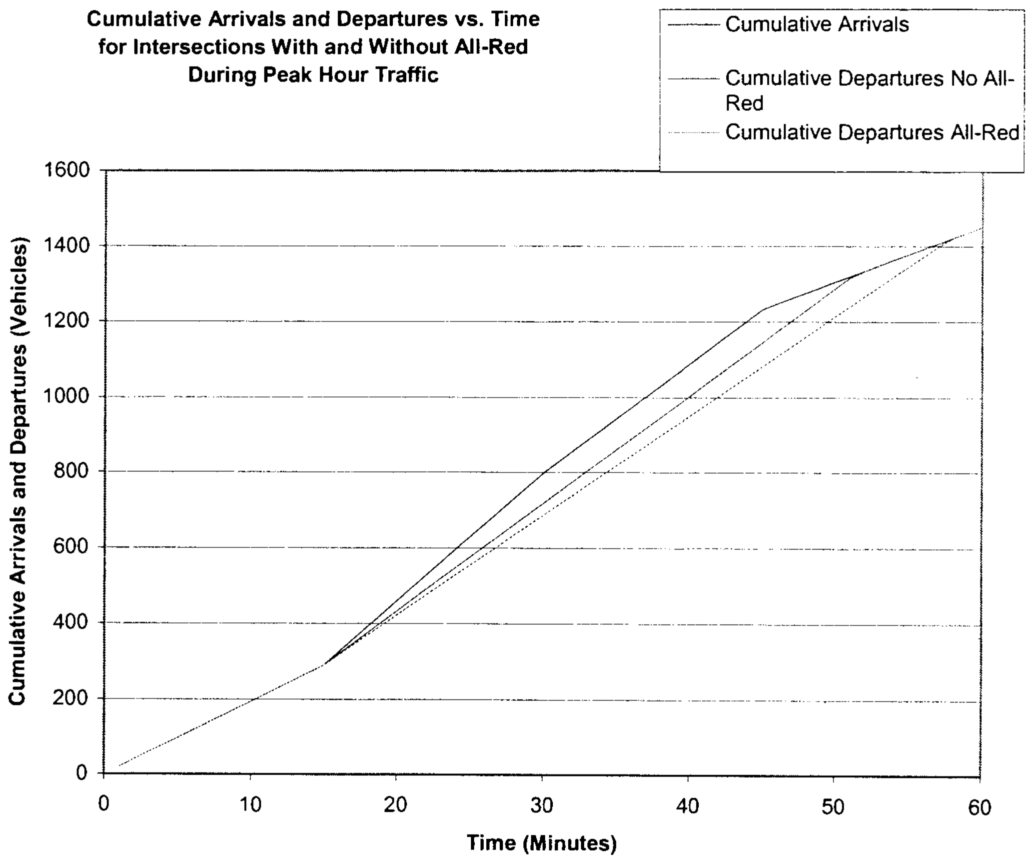


Figure 7.1: Cumulative Arrivals and Departures for Intersections With and Without All-Red Clearance Intervals During Peak Hour Traffic

If the intersection modeled above were representative of a typical intersection in the city of Minneapolis, it would cost users an additional $21,200,000 per year if all-red clearance intervals were added at the remaining 104 intersections that do not have an all-red clearance interval. This number might appear to be rather large, but the cost of congestion in the Twin City Metropolitan Area is $1.2 Billion per year (Schrank and Lomax, 2003). This $21,200,000 does not include the direct costs incurred by the city to implement the addition of the all-red clearance interval. At this point in time to cost of implementation is unknown, but it is expected that the city will need to install a number of new controllers and retime intersections throughout the network to incorporate the changes in the system.

There does appear to be small safety benefit experienced by intersections in the first year after the addition of the all-red clearance interval. According to the before and after study, this benefit is a reduction in relevant crashes of 1.09 crashes. Assuming that Minneapolis intersections experience the same percentages of fatalities, injuries, and property damage only (PDO) crashes as the U.S. average, the average cost of an intersection crash in Minneapolis is $72,819. If the all-red clearance interval is added at the remaining 104 intersections the $21,200,000 increased user cost can be slightly offset by $8,255,000 for the first year. This means that the increase in congestion cost for the City of Minneapolis is expected to be $12,945,000. After the first year there will not be a reduction in intersection crashes due to the all-red clearance interval, and the yearly cost of adding the all-red clearance interval at these 104 intersections is expected to be $21,200,000.

Chapter 8: Conclusions and Recommendations

8.1. Summary of Findings

A simple comparison of crashes and crash rates between signals with and without all-red clearance intervals is misleading, most likely due to spurious correlation between dangerous intersections and those with all-red clearance intervals. Clearly all-red clearance intervals are most likely implemented where safety is a problem. The problem is that those intersections with the all-red clearance interval are also the most congested; where the cost of lost time is perhaps highest. However, the very phenomenon that reduces the benefit of the all-red clearance interval to safety (e.g. pushing the limits) also serves to increase capacity. There are some capacity benefits of the all-red clearance interval, namely, sneakers.

There are short-term safety benefits of the all-red clearance interval, but these benefits are not long lasting and are potentially overshadowed by loss of capacity. The short-term nature of the benefits is most likely due to driver familiarity, which may lead to equilibrium as drivers push the limit.

8.2. Recommendations

The results of this study do not support the hypothesis that an all-red clearance interval increases safety at intersections. There are two options for the City of Minneapolis to consider regarding the conversion of their remaining signals. The first option would be to not convert the signals because the data does not show a safety benefit of using the all-red clearance interval. The second opetion would be to install all-red clearance intervals at the remaining intersections during off-peak hours. If the all-red clearance interval is only installed during off-peak hours, there will not be a delay cost associated with installing the all-red clearance interval. Additionally, literature states that intersections crashes are lower during the peak-hours when intersections are operating at capacity. Implementing the all-red clearance interval during off-peak hours would not affect congestion because the intersections are operating at higher levels of service during off-peak hours. A major downfall of this recommendation is that driver expectation will be violated.

8.3. Future Research

Although the data do not support the notion that there are safety benefits of the all-red clearance interval, more research should be preformed before removing the all-red clearance interval at intersections. Several potentially rewarding areas of future research might include investigating the effects of additional variables, exploring the effects of different lengths of the all-red clearance interval, and adding red light running cameras at intersections.

8.3.1.Investigating the Effects of Additional Variables

To our understanding the proper statistical models were used in the analysis. Through the use of the statistical models, we cannot show there is a long-term safety benefit by implementing the all-red clearance interval at intersections. Despite what the statistics state, a majority of agencies use the all-red clearance intervals with the idea that it improves intersection safety. Maybe if additional variables are investigated, a long-term safety benefit will be identified. These additional variables might include:

- Intersection grade
- Presence of on-street parking

- Proper signal timing at the intersections including whether the length of the all-red was adequate
- Warrants for signals
- Number of approach lanes
- Type of signal (fixed versus fully or semi actuated)
- Intersection width
- Observed approach speeds versus posted speeds
- Weather conditions
- Cycle length

It might be possible that with the inclusion of these variables the negative safety benefit of the all-red clearance interval might be reversed or at least nullified.

8.3.2. Exploring the Effects of Different Lengths of the All-Red Clearance Interval

Another possible area of future research involves exploring the effects of different lengths of the all-red clearance interval. This was not investigated in this study because each intersection had three different timing schemes for each phase. Crashes would have had to be broken down into time of day and direction of travel (direction of travel was not always available from the crash data). Therefore, this type of analysis was not possible in this situation, but might be an area of future research.

8.3.3. Red Light Running Cameras

According to the Insurance Institute for Highway Safety, in international countries the addition of red light running cameras reduces red light violations by 40-50 percent and injury crashes by 25-30 percent (2003). In addition to showing a reduction in crashes, red light running cameras do not have any adverse affects on intersection delay. Instead of adding all-red clearance intervals at intersections, red light running cameras should be installed to reduce intersection crashes. A study could be conducted in Minneapolis to determine the effectiveness of red light running cameras. Perhaps red light running cameras are more effective in reducing intersection crashes than the all-red clearance interval.

8.4. Conclusions

At this point in time the data do not show that t he all-red clearance interval is effective in reducing intersection crashes. When looking at the descriptive statistics for both the cross section study and the before and after study, the all-red clearance interval does not appear to be effective in increasing safety at intersections in Minneapolis. In the cross-section study, a short safety benefit of reducing approximately 1 crash per intersection in the first year following implementation was noted. Unfortunately, after the first year, intersection crashes increased back to pre-implementation levels. In all four statistical models intersections without the all-red clearance interval had a lower number of relevant crashes. It is possible that the all-red clearance interval does not appear to increase safety at intersections because the all-red clearance interval is added at intersections that have higher crashes and crash rates.

A cost of implementation study identified the user costs of implementing the all-red clearance interval at intersections without the all-red clearance interval. This reveled that capacity relations due to lost time during the signal cycle are long lasting and may outweigh the temporary safety benefits. Because there is a significant capacity reduction associated with implementing the all-red clearance interval, care should be taken in the decision to add the all-red clearance interval at intersections.

Appendix A: Intersections

A.1. Usable Intersections

Table A1: Usable Intersections

NUM	INTERSECTION NAME	All_Red	AR_Added	Confident
26	E Lake St & 42 Ave S	N	N/A	Y
28	E 31 St & 10 Ave S	N	N/A	Y
34	Lyndale Ave S & W 40 St	N	N/A	Y
52	Cedar Ave & E 36 St	N	N/A	Y
74	W 50 St & Penn Ave S	N	N/A	Y
112	E 25 St & 31 Ave S	N	N/A	Y
116	E Lake St & 39 Ave S	N	N/A	Y
150	Chicago Ave & E 33 St	N	N/A	Y
176	Washington Ave N & 26 Ave N	N	N/A	Y
177	E Hennepin Ave & Hoover St	N	N/A	Y
203	E Franklin Ave & Cedar Ave	N	N/A	Y
227	26 Ave S & E 25 St	N	N/A	Y
231	Central Ave NE & 20 Ave NE	N	N/A	Y
267	Nicollet Ave & 58 St	N	N/A	Y
268	Huron Blvd & Fulton St	N	N/A	Y
299	Grand Ave & W 34 St	N	N/A	Y
339	Plymouth Ave & 2 St N	N	N/A	Y
345	Lyndale Ave N & 14 Ave N	N	N/A	Y
361	3 Ave S & E 24 St	N	N/A	Y
368	Lyndale Ave S & W 48 St	N	N/A	Y
389	27 Ave SE & Essex St	N	N/A	Y
463	Lyndale Ave S & W 38 St	N	N/A	Y
468	Nicollet Ave & 42 St	N	N/A	Y
469	Nicollet Ave & 40 St	N	N/A	Y
490	W 35 St & Grand Ave	N	N/A	Y
497	W 36 St & Grand Ave	N	N/A	Y
499	W Broadway & Dupont Ave N	N	N/A	Y
577	Penn Ave N & 12 Ave N	N	N/A	Y
791	Xerxes Ave S & W 44 St	N	N/A	Y
797	Penn Ave N & Golden Valley Rd	N	N/A	Y
837	Lyndale Ave S & W 32 St	N	N/A	Y
841	Cedar Ave & E 42 St	N	N/A	Y
870	42 Ave S & E 38 St	N	N/A	Y
919	E 38 St & 36 Ave S	N	N/A	Y
942	26 Ave N & 4 St N	N	N/A	Y
970	42 Ave S & E 33 St	N	N/A	Y
975	Xerxes Ave S & W 49 St	N	N/A	Y
981	Glenwood Ave & Morgan Ave N	N	N/A	Y
2	W 50 St & Bryant Ave S	Y	8/27/1991	Y
5	W 50 St & Dupont Ave S	Y	10/5/1995	Y

9	W 31 St & Bryant Ave S	Y	5/19/2003	Y
11	W 50 St & France Ave S	Y	11/6/1970	N
17	Penn Ave N & Glenwood Ave	Y	5/5/2003	Y
19	W Lake St & Drew Ave S	Y	2/3/1993	N
21	Chicago Ave & E 25 St	Y	7/29/1993	N
37	Emerson Ave N & 16 Ave N	Y	3/11/1994	N
42	Lowry Ave N & James Ave N	Y	4/3/1987	N
43	W 50 St & Chowen Ave S	Y	4/14/1980	Y
50	Lyndale Ave S & W 50 St	Y	1/28/1988	Y
51	Lyndale Ave S & W 24 St	Y	2/13/1984	Y
58	Lyndale Ave N & Dowling Ave	Y	12/20/1995	N
61	E 54 St & 12 Ave S	Y	10/3/1998	Y
64	Bloomington Ave & E 31 St	Y	12/15/1992	N
68	Lyndale Ave S & W 56 St	Y	10/3/1995	Y
75	Lowry Ave N & Penn Ave N	Y	12/5/1986	Y
82	University Ave NE & 20 Ave NE	Y	9/20/1993	Y
83	Cedar Ave & E 32 St	Y	5/7/1992	N
89	E 38 St & 3 Ave S	Y	7/10/1995	N
94	Lyndale Ave N & 24 Ave N	Y	11/10/1994	N
95	W Broadway & Emerson Ave N	Y	1/9/1997	N
97	Lowry Ave NE & 2 St NE	Y	7/10/1991	Y
98	Nicollet Ave & Franklin Ave	Y	8/23/1997	N
102	University Ave NE & 3 Ave NE	Y	7/16/1994	N
104	E Hennepin Ave & 15 Ave	Y	10/7/1999	N
109	E Lake St & 31 Ave S	Y	11/9/1962	N
111	Washington Ave S & 10 Ave S	Y	9/30/1999	N
115	E Lake St & 36 Ave S	Y	6/27/2003	Y
121	W 50 St & Xerxes Ave S	Y	4/14/1980	Y
122	W 50 St & Zenith Ave S	Y	9/4/1985	N
125	Chicago Ave & E 34 St	Y	6/16/1972	N
143	Bloomington Ave & E 38 St	Y	1/26/1993	N
144	4 Ave S & E 38 St	Y	11/18/1992	N
146	Lyndale Ave N & 42 Ave N	Y	5/1/1984	N
156	University Ave SE & 27 Ave SE	Y	5/17/1994	N
159	Chicago Ave & E 39 St	Y	11/3/1995	N
161	E Franklin Ave & 4 Ave S	Y	10/8/1994	N
162	Chicago Ave & E 38 St	Y	3/16/1995	Y
178	Hennepin Ave & W 31 St	Y	4/10/1995	N
183	Washington Ave SE & Ontario St	Y	9/3/1993	N
188	Penn Ave N & 42 Ave N	Y	1/8/1990	Y
189	Lyndale Ave N & 36 Ave N	Y	11/22/1995	N
211	W Broadway & Lyndale Ave N	Y	7/13/1995	N
215	Washington Ave SE & Oak St	Y	2/12/1992	N
216	Cedar Ave & E 38 St	Y	5/5/1988	Y
217	Cedar Ave & E Lake St	Y	6/12/1997	N
218	W 36 St & Hennepin Ave	Y	4/13/1992	N

219	Bloomington Ave & E 35 St	Y	1/21/1993	N
226	Fremont Ave N & 42 Ave N	Y	10/22/1998	N
233	Lyndale Ave N & Plymouth Ave	Y	10/21/1980	Y
234	Washington Ave S & 11 Ave S	Y	11/4/1998	N
236	E Franklin Ave & 3 Ave S	Y	1/28/1988	Y
237	10 Ave N & 5 St N	Y	6/9/1980	Y
243	E 46 St & 4 Ave S	Y	11/30/1990	Y
248	Penn Ave N & 26 Ave N	Y	12/19/1988	Y
254	E Franklin & Clinton Ave	Y	11/1/2002	Y
255	Fremont Ave N & 36 Ave N	Y	10/22/1998	N
259	Como Ave & 18 Ave SE	Y	8/7/1992	N
261	Nicollet Ave & 38 St	Y	5/29/2003	Y
262	Emerson Ave N & 24 Ave N	Y	10/15/1996	N
265	Lowry Ave N & 4 St N	Y	12/12/1975	N
270	Huron Blvd & Washington Ave SE	Y	7/2/1992	N
272	Washington Ave N & Lowry Ave N	Y	3/12/1981	Y
281	Nicollet Ave & 34 St	Y	5/31/2002	Y
296	Lyndale Ave N & 18 Ave N	Y	9/26/1991	N
298	W Franklin Ave & Dupont Ave S	Y	2/11/1987	N
308	Lowry Ave NE & Monroe St	Y	2/29/1988	Y
310	Lowry Ave NE & Washington St	Y	12/29/1995	N
313	W 50 St & Upton Ave S	Y	1/8/1993	N
315	Lyndale Ave N & 29 Ave N	Y	11/10/1994	N
333	Lyndale Ave S & W 46 St	Y	8/6/1981	Y
335	Central Ave NE & 14 Ave NE	Y	3/15/1994	N
342	E Lake St & 27 Ave S	Y	1/3/1995	Y
349	Lyndale Ave S & W 36 St	Y	7/14/1981	Y
354	Lyndale Ave N & 26 Ave N	Y	11/21/1994	N
355	Lyndale Ave S & W 33 St	Y	11/4/1976	N
356	W 36 St & Bryant Ave S	Y	4/8/2003	Y
369	26 Ave S & E 26 St	Y	8/17/1983	Y
373	Lyndale Ave S & W 31 St	Y	1/11/1989	Y
378	Nicollet Ave & 31 St	Y	2/25/1998	N
381	Lyndale Ave S & W Franklin Ave	Y	1/25/1995	N
382	Broadway St NE & Buchanan St	Y	6/27/1994	N
388	Upton Ave S & W 43 St	Y	7/30/1993	Y
412	Hennepin Ave & W 34 St	Y	9/6/1979	N
414	Nicollet Ave & 15 St	Y	3/11/1998	N
439	E Lake St & 22 Ave S	Y	12/3/1986	N
441	Dowling Ave & Emerson Ave N	Y	1/13/1982	N
443	Washington Ave N & 2 Ave N	Y	5/11/1998	N
446	Central Ave NE & 18 Ave NE	Y	8/22/1995	N
457	E Lake St & Stevens Ave	Y	2/4/1997	N
458	E Lake St & 3 Ave S	Y	3/10/1997	N
459	Cedar Ave & E 31 St	Y	8/26/1987	Y
467	Hennepin Ave & W 27 St	Y	5/21/1984	N

476	Lowry Ave N & Emerson Ave N	Y	12/5/1996	N
478	Stinson Pkwy & Lowry Ave NE	Y	9/21/1979	N
482	Plymouth Ave & Penn Ave N	Y	7/14/1994	Y
485	E Lake St & Bloomington Ave	Y	7/9/1997	N
486	Bloomington Ave & E 36 St	Y	6/2/1970	N
487	W 35 St & Bryant Ave S	Y	10/15/1981	Y
489	E Franklin Ave & Chicago Ave	Y	11/27/1978	Y
491	E Franklin Ave & 11 Ave S	Y	1/18/1989	Y
493	W Broadway & Washington Ave N	Y	10/19/1999	N
495	Hennepin Ave & Lagoon Ave	Y	2/20/1992	N
498	Broadway St & Central Ave NE	Y	7/1/1998	N
572	W 38 St & Pleasant Ave	Y	3/27/1985	N
573	E 38 St & 13 Ave S	Y	4/5/1988	N
576	Penn Ave N & Oak Park Ave	Y	8/27/1994	N
582	E 36 St & 4 Ave S	Y	9/23/1981	Y
588	University Ave NE & 17 Ave NE	Y	4/13/1989	N
590	W Lake St & W Dean Pkwy	Y	1/22/1992	N
592	W 50 St & Vincent Ave S	Y	2/1/1993	N
595	University Ave SE & 25 Ave SE	Y	7/1/1992	N
598	Bloomington Ave & E 42 St	Y	5/8/2003	Y
600	Broadway St NE & Washington St	Y	7/26/1991	Y
611	Oak St & Fulton St	Y	12/5/1989	N
623	E Lake St & 21 Ave S	Y	7/14/1997	N
634	Cedar Ave & E 34 St	Y	2/10/1989	N
639	Johnson St & 27 Ave NE	Y	2/20/1991	N
645	Hennepin Ave & 13 St	Y	6/8/1998	N
659	Lyndale Ave S & W 22 St	Y	7/22/1991	N
670	W Lake St & Bryant Ave S	Y	8/19/1996	N
674	E Lake St & 13 Ave S	Y	7/10/1997	N
735	3 Ave S & Washington Ave S	Y	3/29/1990	Y
736	3 Ave S & 2 St S	Y	5/5/2003	Y
738	Johnson St & 29 Ave NE	Y	2/6/1991	N
751	Chicago Ave & E 48 St	Y	9/2/1993	Y
783	E 46 St & 42 Ave S	Y	9/20/1972	N
803	E Lake St & 10 Ave S	Y	3/31/1997	N
806	E Lake St & 4 Ave S	Y	8/23/1996	N
807	Lyndale Ave N & 41 Ave N	Y	8/10/1999	N
808	E Lake St & 17 Ave S	Y	7/8/1997	N
809	Johnson St & 18 Ave NE	Y	11/18/1987	N
810	Lyndale Ave S & W 43 St	Y	5/1/1997	Y
812	Chicago Ave & E Lake St	Y	7/22/1996	N
813	W 50 St & James Ave S	Y	7/22/1996	N
820	Olson Mem Hwy & Penn Ave N	Y	9/20/1999	N
827	Chicago Ave & E 24 St	Y	5/28/1981	Y
831	Chicago Ave & E 36 St	Y	4/5/1990	Y
832	Chicago Ave & E 42 St	Y	11/12/1994	Y

838	Cedar Ave & Minnehaha Pkwy	Y	4/25/1988	N
840	Cedar Ave & E 26 St	Y	5/24/1989	Y
842	University Ave NE & 13 Ave NE	Y	5/24/1989	Y
846	Cedar Ave & E 35 St	Y	3/11/1988	Y
848	Lowry Ave NE & Johnson St	Y	12/18/1991	N
850	2 St NE & 8 Ave NE	Y	7/11/1995	N
851	Johnson St & 23 Ave NE	Y	7/30/1974	N
855	Marshall St & 13 Ave NE	Y	3/5/1981	Y
857	Cedar Ave & E 46 St	Y	7/16/1994	N
860	Lowry Ave & University Ave NE	Y	3/8/1951	N
861	Nicollet Ave & 46 St	Y	3/27/1981	Y
864	2 St NE & 13 Ave NE	Y	11/20/1970	N
865	E 36 St & 3 Ave S	Y	8/12/1983	Y
871	E Lake St & 44 Ave S	Y	10/8/1994	N
872	E Lake St & 33 Ave S	Y	5/28/2003	Y
873	E Lake St & 30 Ave S	Y	10/22/1986	N
875	Penn Ave S & W 58 St	Y	8/28/1996	N
877	University Ave NE & 5 Ave NE	Y	7/16/1994	N
882	Penn Ave S & W 54 St	Y	5/27/1994	Y
884	Central Ave NE & 28 Ave NE	Y	12/12/1994	N
885	Franklin Ave SE & Seymour Ave	Y	9/7/1950	N
886	Bloomington Ave & E 24 St	Y	11/16/1981	Y
890	Nicollet Ave & Diamond Lake Rd	Y	2/19/1993	N
892	34 Ave S & E 50 St	Y	5/14/2003	Y
895	Broadway St NE & Fillmore St	Y	12/29/1994	Y
896	W Broadway & 2 St N	Y	3/14/1990	Y
897	Lowry Ave N & 2 St N	Y	6/2/1986	Y
898	8 Ave NE & Marshall St	Y	9/26/1985	Y
900	University Ave NE & 8 Ave NE	Y	7/13/1996	Y
902	Penn Ave S & W 56 St	Y	12/22/1995	Y
905	Portland Ave & E 47 St	Y	12/21/1995	N
914	Lyndale Ave S & W 35 St	Y	1/9/1967	N
917	France Ave S & W 44 St	Y	4/9/1990	N
920	E 38 St & 28 Ave S	Y	3/23/1995	Y
923	E Lake St & Elliot Ave	Y	3/17/1997	N
931	Lowry Ave N & Russell Ave N	Y	3/17/1994	N
936	42 Ave S & E 42 St	Y	9/18/1971	N
938	E Franklin Ave & 22 Ave S	Y	7/11/1991	Y
940	Johnson St & 33 Ave NE	Y	12/21/1991	N
941	37 Ave NE & Johnson St	Y	9/2/1994	N
943	Penn Ave S & W 60 St	Y	6/10/1969	N
945	Fremont Ave N & Dowling Ave	Y	2/19/1999	N
951	Washington Ave N & 6 Ave N	Y	11/17/1994	N
966	Penn Ave N & Dowling Ave	Y	7/27/1994	Y
967	Lyndale Ave S & W 61 St	Y	10/6/1999	N
969	Golden Valley Rd & Russell Ave	Y	7/18/1972	N

980	28 Ave S & E 42 St	Y	4/18/1975	N
983	W 39 St & Sheridan Ave S	Y	8/13/1993	Y
987	Chicago Ave & E 54 St	Y	4/7/1987	Y
989	W 31 St & Pillsbury Ave	Y	6/4/1997	Y

A.2. Cross-Section Study Data

Table A2: Cross-Section Study Data

NUM	Year	Rel_A	TOT_A	DEV	Rel_ARt	TOT_ARt	TRT	D1	D2	LIGHTS
26	1999	2	4	15783	0.347	0.694	0	0	1	1
28	1999	0	1	10729	0.000	0.255	0	0	0	1
34	1999	2	2	14452	0.379	0.379	0	0	1	1
52	1999	5	7	17637	0.777	1.087	0	0	0	1
74	1999	0	1	19348	0.000	0.142	0	0	0	1
112	1999	0	1	5610	0.000	0.488	0	0	0	1
116	1999	1	2	12455	0.220	0.440	0	0	1	1
150	1999	3	6	9745	0.843	1.687	0	0	0	1
176	1999	4	5	8847	1.239	1.548	0	0	1	1
177	1999	1	1	15284	0.179	0.179	0	0	1	1
203	1999	21	24	29949	1.921	2.195	0	1	0	1
227	1999	0	3	7606	0.000	1.081	0	0	0	1
231	1999	1	1	15767	0.174	0.174	0	0	1	1
267	1999	5	6	15545	0.881	1.057	0	0	0	1
268	1999	4	4	24559	0.446	0.446	0	1	0	1
299	1999	0	0	2108	0.000	0.000	0	0	0	0
339	1999	4	4	27267	0.402	0.402	0	1	0	1
345	1999	1	2	10933	0.251	0.501	0	0	1	1
361	1999	2	2	9127	0.600	0.600	0	0	0	1
368	1999	0	1	14945	0.000	0.183	0	0	1	1
389	1999	0	3	4840	0.000	1.698	0	0	0	1
463	1999	5	7	15925	0.860	1.204	0	0	1	1
468	1999	0	1	11837	0.000	0.231	0	0	1	1
469	1999	1	2	10173	0.269	0.539	0	0	1	1
490	1999	1	1	7654	0.358	0.358	0	0	0	1
497	1999	3	3	10649	0.772	0.772	0	0	0	1
499	1999	1	2	19442	0.141	0.282	0	0	1	1
577	1999	1	1	12963	0.211	0.211	0	0	1	1
791	1999	0	0	15593	0.000	0.000	0	0	0	1
797	1999	5	13	16486	0.831	2.160	0	1	0	1
837	1999	0	1	16290	0.000	0.168	0	0	0	1
841	1999	8	10	21868	1.002	1.253	0	0	0	1
870	1999	1	1	4564	0.600	0.600	0	0	1	1
919	1999	2	3	5990	0.915	1.372	0	0	0	1
942	1999	1	2	3681	0.744	1.489	0	0	0	0
970	1999	0	0	9660	0.000	0.000	0	0	0	0

975	1999	0	0	8938	0.000	0.000	0	0	0	0
981	1999	3	4	7670	1.072	1.429	0	0	0	1
26	2000	3	4	16051	0.512	0.683	0	0	1	1
28	2000	2	3	10911	0.502	0.753	0	0	0	1
34	2000	0	1	14697	0.000	0.186	0	0	1	1
52	2000	6	9	17936	0.916	1.375	0	0	0	1
74	2000	2	3	19677	0.278	0.418	0	0	0	1
112	2000	1	1	5705	0.480	0.480	0	0	0	1
116	2000	2	3	12666	0.433	0.649	0	0	1	1
150	2000	4	5	9911	1.106	1.382	0	0	0	1
176	2000	2	5	8997	0.609	1.523	0	0	1	1
177	2000	2	5	15543	0.353	0.881	0	0	1	1
203	2000	17	21	30458	1.529	1.889	0	1	0	1
227	2000	2	4	7735	0.708	1.417	0	0	0	1
231	2000	1	1	16035	0.171	0.171	0	0	1	1
267	2000	3	3	15809	0.520	0.520	0	0	0	1
268	2000	1	2	24976	0.110	0.219	0	1	0	1
299	2000	0	1	2144	0.000	1.278	0	0	0	0
339	2000	2	2	27729	0.198	0.198	0	1	0	1
345	2000	1	1	11118	0.246	0.246	0	0	1	1
361	2000	1	3	9282	0.295	0.885	0	0	0	1
368	2000	2	2	15199	0.361	0.361	0	0	1	1
389	2000	1	2	4922	0.557	1.113	0	0	0	1
463	2000	1	4	16196	0.169	0.677	0	0	1	1
468	2000	1	4	12038	0.228	0.910	0	0	1	1
469	2000	2	2	10346	0.530	0.530	0	0	1	1
490	2000	0	0	7784	0.000	0.000	0	0	0	1
497	2000	4	4	10829	1.012	1.012	0	0	0	1
499	2000	3	5	19771	0.416	0.693	0	0	1	1
577	2000	1	3	13183	0.208	0.623	0	0	1	1
791	2000	3	4	15857	0.518	0.691	0	0	0	1
797	2000	4	8	16765	0.654	1.307	0	1	0	1
837	2000	2	5	16566	0.331	0.827	0	0	0	1
841	2000	5	7	22239	0.616	0.862	0	0	0	1
870	2000	1	1	4641	0.590	0.590	0	0	1	1
919	2000	0	2	6092	0.000	0.900	0	0	0	1
942	2000	2	2	3743	1.464	1.464	0	0	0	0
970	2000	0	0	9824	0.000	0.000	0	0	0	0
975	2000	0	0	9090	0.000	0.000	0	0	0	0
981	2000	2	4	7800	0.702	1.405	0	0	0	1
26	2001	1	2	16323	0.168	0.336	0	0	1	1
28	2001	1	1	11096	0.247	0.247	0	0	0	1
34	2001	2	3	14946	0.367	0.550	0	0	1	1
52	2001	3	9	18240	0.451	1.352	0	0	0	1
74	2001	1	6	20010	0.137	0.821	0	0	0	1
112	2001	1	3	5802	0.472	1.417	0	0	0	1

116	2001	1	4	12881	0.213	0.851	0	0	1	1
150	2001	1	2	10079	0.272	0.544	0	0	0	1
176	2001	0	0	9150	0.000	0.000	0	0	1	1
177	2001	2	4	15807	0.347	0.693	0	0	1	1
203	2001	12	18	30974	1.061	1.592	0	1	0	1
227	2001	1	2	7867	0.348	0.697	0	0	0	1
231	2001	0	0	16307	0.000	0.000	0	0	1	1
267	2001	5	5	16077	0.852	0.852	0	0	0	1
268	2001	1	1	25400	0.108	0.108	0	1	0	1
299	2001	0	1	2180	0.000	1.257	0	0	0	0
339	2001	5	6	28200	0.486	0.583	0	1	0	1
345	2001	0	0	11307	0.000	0.000	0	0	1	1
361	2001	2	4	9440	0.580	1.161	0	0	0	1
368	2001	1	3	15457	0.177	0.532	0	0	1	1
389	2001	0	3	5006	0.000	1.642	0	0	0	1
463	2001	6	7	16470	0.998	1.164	0	0	1	1
468	2001	3	5	12242	0.671	1.119	0	0	1	1
469	2001	0	0	10521	0.000	0.000	0	0	1	1
490	2001	1	3	7916	0.346	1.038	0	0	0	1
497	2001	3	4	11013	0.746	0.995	0	0	0	1
499	2001	4	4	20107	0.545	0.545	0	0	1	1
577	2001	2	2	13407	0.409	0.409	0	0	1	1
791	2001	1	1	16126	0.170	0.170	0	0	0	1
797	2001	3	4	17050	0.482	0.643	0	1	0	1
837	2001	1	2	16847	0.163	0.325	0	0	0	1
841	2001	5	8	22616	0.606	0.969	0	0	0	1
870	2001	0	1	4720	0.000	0.580	0	0	1	1
919	2001	0	0	6195	0.000	0.000	0	0	0	1
942	2001	0	3	3807	0.000	2.159	0	0	0	0
970	2001	0	0	9990	0.000	0.000	0	0	0	0
975	2001	0	1	9244	0.000	0.296	0	0	0	0
981	2001	2	3	7933	0.691	1.036	0	0	0	1
26	2002	0	2	16600	0.000	0.330	0	0	1	1
28	2002	1	2	11284	0.243	0.486	0	0	0	1
34	2002	2	4	15200	0.360	0.721	0	0	1	1
52	2002	3	6	18550	0.443	0.886	0	0	0	1
74	2002	6	8	20350	0.808	1.077	0	0	0	1
112	2002	1	1	5900	0.464	0.464	0	0	0	1
116	2002	1	1	13100	0.209	0.209	0	0	1	1
150	2002	0	5	10250	0.000	1.336	0	0	0	1
176	2002	2	3	9305	0.589	0.883	0	0	1	1
177	2002	0	0	16075	0.000	0.000	0	0	1	1
203	2002	14	17	31500	1.218	1.479	0	1	0	1
227	2002	0	0	8000	0.000	0.000	0	0	0	1
231	2002	2	2	16584	0.330	0.330	0	0	1	1
267	2002	3	3	16350	0.503	0.503	0	0	0	1

268	2002	2	2	25831	0.212	0.212	0	1	0	1
299	2002	0	1	2217	0.000	1.236	0	0	0	0
339	2002	2	2	28679	0.191	0.191	0	1	0	1
345	2002	0	0	11499	0.000	0.000	0	0	1	1
361	2002	2	6	9600	0.571	1.712	0	0	0	1
368	2002	0	0	15719	0.000	0.000	0	0	1	1
389	2002	0	0	5090	0.000	0.000	0	0	0	1
463	2002	1	2	16750	0.164	0.327	0	0	1	1
468	2002	2	2	12450	0.440	0.440	0	0	1	1
469	2002	1	2	10700	0.256	0.512	0	0	1	1
490	2002	1	3	8050	0.340	1.021	0	0	0	1
497	2002	5	5	11200	1.223	1.223	0	0	0	1
499	2002	7	8	20448	0.938	1.072	0	0	1	1
577	2002	1	1	13635	0.201	0.201	0	0	1	1
791	2002	0	1	16400	0.000	0.167	0	0	0	1
797	2002	4	7	17339	0.632	1.106	0	1	0	1
837	2002	0	0	17133	0.000	0.000	0	0	0	1
841	2002	5	10	23000	0.596	1.191	0	0	0	1
870	2002	1	1	4800	0.571	0.571	0	0	1	1
919	2002	1	1	6300	0.435	0.435	0	0	0	1
942	2002	0	0	3872	0.000	0.000	0	0	0	0
970	2002	1	1	10160	0.270	0.270	0	0	0	0
975	2002	0	0	9401	0.000	0.000	0	0	0	0
981	2002	2	4	8067	0.679	1.358	0	0	0	1
43	1999	2	2	14514	0.378	0.378	1	0	0	1
51	1999	11	17	26812	1.124	1.737	1	0	1	1
75	1999	18	22	22336	2.208	2.699	1	1	0	1
109	1999	3	5	18160	0.453	0.754	1	0	1	1
121	1999	3	5	21535	0.382	0.636	1	0	0	0
125	1999	0	2	9072	0.000	0.604	1	0	0	1
233	1999	7	7	18758	1.022	1.022	1	1	0	1
237	1999	0	0	10449	0.000	0.000	1	0	0	0
265	1999	1	4	12577	0.218	0.871	1	0	1	1
272	1999	6	8	16147	1.018	1.357	1	1	0	1
298	1999	1	4	9057	0.302	1.210	1	0	0	1
349	1999	3	8	21107	0.389	1.038	1	0	1	1
355	1999	0	2	16156	0.000	0.339	1	0	1	1
412	1999	0	0	8652	0.000	0.000	1	0	1	1
439	1999	1	1	18081	0.152	0.152	1	0	1	1
441	1999	0	1	16834	0.000	0.163	1	0	1	1
459	1999	11	12	18350	1.642	1.792	1	0	0	0
467	1999	7	12	28042	0.684	1.172	1	0	1	1
478	1999	1	1	14939	0.183	0.183	1	1	0	1
486	1999	1	1	8082	0.339	0.339	1	0	1	1
572	1999	0	0	6859	0.000	0.000	1	0	0	1
582	1999	4	5	10268	1.067	1.334	1	0	0	1

783	1999	3	3	16543	0.497	0.497	1	0	0	1
809	1999	3	6	18903	0.435	0.870	1	1	0	1
851	1999	2	2	14462	0.379	0.379	1	0	0	1
855	1999	6	6	9344	1.759	1.759	1	0	0	1
860	1999	16	21	30312	1.446	1.898	1	1	0	1
861	1999	7	11	22058	0.869	1.366	1	1	0	1
864	1999	0	1	5366	0.000	0.511	1	0	0	1
865	1999	4	4	11885	0.922	0.922	1	0	0	1
873	1999	4	5	15134	0.724	0.905	1	0	1	1
886	1999	7	9	14452	1.327	1.706	1	0	0	1
897	1999	5	6	20933	0.654	0.785	1	1	0	1
898	1999	3	4	16534	0.497	0.663	1	0	0	1
914	1999	2	5	16686	0.328	0.821	1	0	1	1
943	1999	1	4	18112	0.151	0.605	1	0	0	1
969	1999	0	0	5712	0.000	0.000	1	0	1	1
980	1999	4	6	13406	0.817	1.226	1	0	0	1
43	2000	1	2	14761	0.186	0.371	1	0	0	1
51	2000	10	21	27267	1.005	2.110	1	0	1	1
75	2000	16	20	22715	1.930	2.412	1	1	0	1
109	2000	1	2	18468	0.148	0.297	1	0	1	1
121	2000	8	12	21900	1.001	1.501	1	0	0	0
125	2000	2	3	9226	0.594	0.891	1	0	0	1
233	2000	6	7	19076	0.862	1.005	1	1	0	1
237	2000	1	2	10627	0.258	0.516	1	0	0	0
265	2000	4	4	12790	0.857	0.857	1	0	1	1
272	2000	5	6	16421	0.834	1.001	1	1	0	1
298	2000	2	5	9211	0.595	1.487	1	0	0	1
349	2000	4	6	21465	0.511	0.766	1	0	1	1
355	2000	1	2	16431	0.167	0.333	1	0	1	1
412	2000	0	0	8799	0.000	0.000	1	0	1	1
439	2000	6	8	18388	0.894	1.192	1	0	1	1
441	2000	1	1	17119	0.160	0.160	1	0	1	1
459	2000	7	9	18661	1.028	1.321	1	0	0	0
467	2000	3	5	28518	0.288	0.480	1	0	1	1
478	2000	3	3	15192	0.541	0.541	1	1	0	1
486	2000	1	2	8219	0.333	0.667	1	0	1	1
572	2000	0	0	6976	0.000	0.000	1	0	0	1
582	2000	3	6	10443	0.787	1.574	1	0	0	1
783	2000	2	3	16824	0.326	0.489	1	0	0	1
809	2000	2	5	19224	0.285	0.713	1	1	0	1
851	2000	3	3	14707	0.559	0.559	1	0	0	1
855	2000	4	4	9503	1.153	1.153	1	0	0	1
860	2000	13	17	30827	1.155	1.511	1	1	0	1
861	2000	9	11	22432	1.099	1.343	1	1	0	1
864	2000	0	1	5457	0.000	0.502	1	0	0	1
865	2000	7	7	12086	1.587	1.587	1	0	0	1

873	2000	0	3	15391	0.000	0.534	1	0	1	1
886	2000	8	12	14697	1.491	2.237	1	0	0	1
897	2000	6	8	21289	0.772	1.030	1	1	0	1
898	2000	4	5	16815	0.652	0.815	1	0	0	1
914	2000	5	6	16969	0.807	0.969	1	0	1	1
943	2000	0	0	18420	0.000	0.000	1	0	0	1
969	2000	0	3	5808	0.000	1.415	1	0	1	1
980	2000	3	7	13633	0.603	1.407	1	0	0	1
43	2001	4	4	15011	0.730	0.730	1	0	0	1
51	2001	11	17	27729	1.087	1.680	1	0	1	1
75	2001	13	16	23100	1.542	1.898	1	1	0	1
109	2001	2	4	18781	0.292	0.584	1	0	1	1
121	2001	1	3	22272	0.123	0.369	1	0	0	0
125	2001	2	3	9383	0.584	0.876	1	0	0	1
233	2001	9	10	19400	1.271	1.412	1	1	0	1
237	2001	0	1	10807	0.000	0.254	1	0	0	0
265	2001	1	3	13007	0.211	0.632	1	0	1	1
272	2001	7	7	16700	1.148	1.148	1	1	0	1
298	2001	1	2	9367	0.292	0.585	1	0	0	1
349	2001	1	1	21830	0.126	0.126	1	0	1	1
355	2001	0	5	16709	0.000	0.820	1	0	1	1
412	2001	1	3	8948	0.306	0.919	1	0	1	1
439	2001	10	12	18700	1.465	1.758	1	0	1	1
441	2001	1	3	17410	0.157	0.472	1	0	1	1
459	2001	11	13	18978	1.588	1.877	1	0	0	0
467	2001	6	12	29002	0.567	1.134	1	0	1	1
478	2001	1	1	15450	0.177	0.177	1	1	0	1
486	2001	1	2	8358	0.328	0.656	1	0	1	1
572	2001	0	0	7094	0.000	0.000	1	0	0	1
582	2001	6	7	10620	1.548	1.806	1	0	0	1
783	2001	2	3	17110	0.320	0.480	1	0	0	1
809	2001	2	4	19550	0.280	0.561	1	1	0	1
851	2001	1	1	14957	0.183	0.183	1	0	0	1
855	2001	0	1	9664	0.000	0.283	1	0	0	1
860	2001	21	23	31350	1.835	2.010	1	1	0	1
861	2001	9	13	22813	1.081	1.561	1	1	0	1
864	2001	1	3	5550	0.494	1.481	1	0	0	1
865	2001	6	9	12291	1.337	2.006	1	0	0	1
873	2001	4	5	15652	0.700	0.875	1	0	1	1
886	2001	4	6	14946	0.733	1.100	1	0	0	1
897	2001	4	8	21650	0.506	1.012	1	1	0	1
898	2001	1	2	17100	0.160	0.320	1	0	0	1
914	2001	6	6	17257	0.953	0.953	1	0	1	1
943	2001	2	3	18732	0.293	0.439	1	0	0	1
969	2001	0	1	5907	0.000	0.464	1	0	1	1
980	2001	4	7	13865	0.790	1.383	1	0	0	1

43	2002	1	3	15266	0.179	0.538	1	0	0	1
51	2002	10	19	28200	0.972	1.846	1	0	1	1
75	2002	14	16	23492	1.633	1.866	1	1	0	1
109	2002	6	8	19100	0.861	1.148	1	0	1	1
121	2002	1	4	22650	0.121	0.484	1	0	0	0
125	2002	3	4	9542	0.861	1.148	1	0	0	1
233	2002	7	10	19729	0.972	1.389	1	1	0	1
237	2002	0	0	10990	0.000	0.000	1	0	0	0
265	2002	1	1	13228	0.207	0.207	1	0	1	1
272	2002	7	10	16983	1.129	1.613	1	1	0	1
298	2002	0	0	9526	0.000	0.000	1	0	0	1
349	2002	8	8	22200	0.987	0.987	1	0	1	1
355	2002	2	4	16993	0.322	0.645	1	0	1	1
412	2002	3	4	9100	0.903	1.204	1	0	1	1
439	2002	6	7	19017	0.864	1.008	1	0	1	1
441	2002	2	4	17705	0.309	0.619	1	0	1	1
459	2002	8	12	19300	1.136	1.703	1	0	0	0
467	2002	4	5	29494	0.372	0.464	1	0	1	1
478	2002	2	2	15712	0.349	0.349	1	1	0	1
486	2002	1	4	8500	0.322	1.289	1	0	1	1
572	2002	1	1	7214	0.380	0.380	1	0	0	1
582	2002	4	5	10800	1.015	1.268	1	0	0	1
783	2002	2	2	17400	0.315	0.315	1	0	0	1
809	2002	6	6	19882	0.827	0.827	1	1	0	1
851	2002	8	8	15211	1.441	1.441	1	0	0	1
855	2002	3	4	9828	0.836	1.115	1	0	0	1
860	2002	14	20	31882	1.203	1.719	1	1	0	1
861	2002	6	9	23200	0.709	1.063	1	1	0	1
864	2002	2	2	5644	0.971	0.971	1	0	0	1
865	2002	1	3	12500	0.219	0.658	1	0	0	1
873	2002	1	2	15917	0.172	0.344	1	0	1	1
886	2002	5	7	15200	0.901	1.262	1	0	0	1
897	2002	5	7	22017	0.622	0.871	1	1	0	1
898	2002	4	5	17390	0.630	0.788	1	0	0	1
914	2002	6	8	17550	0.937	1.249	1	0	1	1
943	2002	1	2	19050	0.144	0.288	1	0	0	1
969	2002	0	0	6007	0.000	0.000	1	0	1	1
980	2002	2	2	14100	0.389	0.389	1	0	0	1

A.3. Before and After Study Data

Table A3: Before and After Study Data

NUM	B&A	DEV	Rel_A	Rel_ARt	TOT_A	TOT_ARt	TRT	D1	D2	LIGHTS
989	-5	11735	0	0.000	2	0.000	0	0	0	1
810	-5	11569	0	0.000	0	0.000	0	0	0	1
900	-5	13408	3	0.613	5	0.613	0	0	0	1
902	-5	7845	0	0.000	0	0.000	0	0	0	1
5	-5	11685	1	0.235	2	0.234	0	0	0	1
68	-5	14954	3	0.550	3	0.550	0	0	1	1
920	-5	11930	4	0.919	6	0.919	0	0	0	1
162	-5	13851	4	0.791	7	0.791	0	0	0	1
342	-5	16833	2	0.326	4	0.326	0	1	0	1
895	-5	14224	1	0.193	2	0.193	0	0	1	1
832	-5	10647	2	0.515	3	0.515	0	0	0	0
966	-5	12911	5	1.061	10	1.061	0	0	1	1
482	-5	18508	5	0.740	6	0.740	0	0	1	1
882	-5	10847	1	0.253	1	0.253	0	0	0	1
82	-5	11898	3	0.691	4	0.691	0	0	0	1
751	-5	6335	1	0.433	2	0.432	0	0	1	1
983	-5	9797	2	0.559	4	0.559	0	0	0	1
388	-5	8018	1	0.342	1	0.342	0	0	0	1
2	-5	11689	1	0.234	2	0.234	0	0	1	1
600	-5	14684	1	0.187	1	0.187	0	0	1	1
938	-5	9257	3	0.888	5	0.888	0	0	1	1
97	-5	12547	8	1.747	8	1.747	0	0	1	1
989	-4	11934	0	0.000	1	0.000	0	0	0	1
810	-4	11765	0	0.000	0	0.000	0	0	0	1
900	-4	13635	3	0.603	3	0.603	0	0	0	1
902	-4	7978	1	0.343	2	0.343	0	0	0	1
5	-4	11884	1	0.231	1	0.231	0	0	0	1
68	-4	15208	0	0.000	1	0.000	0	0	1	1
920	-4	12133	1	0.226	3	0.226	0	0	0	1
162	-4	14086	4	0.778	4	0.778	0	0	0	1
342	-4	17119	4	0.640	5	0.640	0	1	0	1
895	-4	14466	2	0.379	3	0.379	0	0	1	1
832	-4	10827	4	1.012	6	1.012	0	0	0	0
966	-4	13130	3	0.626	6	0.626	0	0	1	1
482	-4	18823	11	1.601	13	1.601	0	0	1	1
882	-4	11032	1	0.248	1	0.248	0	0	0	1
82	-4	12100	2	0.453	3	0.453	0	0	0	1
751	-4	6442	2	0.851	2	0.851	0	0	1	1
983	-4	9964	0	0.000	0	0.000	0	0	0	1
388	-4	8154	4	1.344	4	1.344	0	0	0	1
2	-4	11887	4	0.922	6	0.922	0	0	1	1

600	-4	14933	3	0.550	5	0.550	0	0	1	1
938	-4	9414	0	0.000	1	0.000	0	0	1	1
97	-4	12760	2	0.429	4	0.429	0	0	1	1
989	-3	12136	0	0.000	5	0.000	0	0	0	1
810	-3	11965	0	0.000	1	0.000	0	0	0	1
900	-3	13867	7	1.383	8	1.383	0	0	0	1
902	-3	8113	1	0.338	1	0.338	0	0	0	1
5	-3	12085	0	0.000	0	0.000	0	0	0	1
68	-3	15466	2	0.354	2	0.354	0	0	1	1
920	-3	12339	0	0.000	2	0.000	0	0	0	1
162	-3	14325	5	0.956	7	0.956	0	0	0	1
342	-3	17409	2	0.315	4	0.315	0	1	0	1
895	-3	14711	2	0.373	2	0.372	0	0	1	1
832	-3	11011	2	0.498	2	0.498	0	0	0	0
966	-3	13353	3	0.616	7	0.616	0	0	1	1
482	-3	19142	12	1.718	14	1.718	0	0	1	1
882	-3	11219	0	0.000	3	0.000	0	0	0	1
82	-3	12305	4	0.891	5	0.891	0	0	0	1
751	-3	6551	3	1.255	5	1.255	0	0	1	1
983	-3	10133	0	0.000	1	0.000	0	0	0	1
388	-3	8292	0	0.000	3	0.000	0	0	0	1
2	-3	12089	2	0.453	4	0.453	0	0	1	1
600	-3	15186	5	0.902	6	0.902	0	0	1	1
938	-3	9574	1	0.286	1	0.286	0	0	1	1
97	-3	12977	7	1.478	9	1.478	0	0	1	1
989	-2	12342	3	0.666	5	0.666	0	0	0	1
810	-2	12168	2	0.450	3	0.450	0	0	0	1
900	-2	14102	5	0.971	7	0.971	0	0	0	1
902	-2	8251	3	0.996	4	0.996	0	0	0	1
5	-2	12290	3	0.669	3	0.669	0	0	0	1
68	-2	15728	2	0.348	2	0.348	0	0	1	1
920	-2	12548	4	0.873	5	0.873	0	0	0	1
162	-2	14568	12	2.257	16	2.257	0	0	0	1
342	-2	17705	3	0.464	4	0.464	0	1	0	1
895	-2	14961	1	0.183	2	0.183	0	0	1	1
832	-2	11198	2	0.489	3	0.489	0	0	0	0
966	-2	13580	8	1.614	10	1.614	0	0	1	1
482	-2	19467	6	0.844	8	0.844	0	0	1	1
882	-2	11409	2	0.480	3	0.480	0	0	0	1
82	-2	12514	0	0.000	2	0.000	0	0	0	1
751	-2	6663	0	0.000	2	0.000	0	0	1	1
983	-2	10305	2	0.532	3	0.532	0	0	0	1
388	-2	8433	0	0.000	0	0.000	0	0	0	1
2	-2	12294	1	0.223	1	0.223	0	0	1	1
600	-2	15444	2	0.355	3	0.355	0	0	1	1
938	-2	9736	1	0.281	2	0.281	0	0	1	1

97	-2	13197	5	1.038	5	1.038	0	0	1	1
989	-1	12552	1	0.218	2	0.218	0	0	0	1
810	-1	12375	1	0.221	1	0.221	0	0	0	1
900	-1	14341	8	1.528	8	1.528	0	0	0	1
902	-1	8391	1	0.327	3	0.327	0	0	0	1
5	-1	12499	0	0.000	0	0.000	0	0	0	1
68	-1	15995	3	0.514	3	0.514	0	0	1	1
920	-1	12761	4	0.859	5	0.859	0	0	0	1
162	-1	14815	5	0.925	9	0.925	0	0	0	1
342	-1	18005	9	1.370	10	1.369	0	1	0	1
895	-1	15215	3	0.540	5	0.540	0	0	1	1
832	-1	11388	3	0.722	3	0.722	0	0	0	0
966	-1	13810	7	1.389	11	1.389	0	0	1	1
482	-1	19797	8	1.107	13	1.107	0	0	1	1
882	-1	11603	1	0.236	2	0.236	0	0	0	1
82	-1	12726	3	0.646	5	0.646	0	0	0	1
751	-1	6776	4	1.617	5	1.617	0	0	1	1
983	-1	10479	0	0.000	2	0.000	0	0	0	1
388	-1	8576	0	0.000	2	0.000	0	0	0	1
2	-1	12502	1	0.219	2	0.219	0	0	1	1
600	-1	15706	1	0.174	2	0.174	0	0	1	1
938	-1	9902	0	0.000	3	0.000	0	0	1	1
97	-1	13421	2	0.408	3	0.408	0	0	1	1
989	0	12765	5	1.073	6	1.073	0/1	0	0	1
810	0	12585	0	0.000	0	0.000	0/1	0	0	1
900	0	14585	9	1.691	11	1.691	0/1	0	0	1
902	0	8533	0	0.000	0	0.000	0/1	0	0	1
5	0	12711	0	0.000	0	0.000	0/1	0	0	1
68	0	16266	2	0.337	3	0.337	0/1	0	1	1
920	0	12978	1	0.211	4	0.211	0/1	0	0	1
162	0	15067	6	1.091	8	1.091	0/1	0	0	1
342	0	18311	4	0.599	4	0.598	0/1	1	0	1
895	0	15473	5	0.885	6	0.885	0/1	0	1	1
832	0	11581	4	0.946	7	0.946	0/1	0	0	0
966	0	14044	7	1.366	9	1.366	0/1	0	1	1
482	0	20133	6	0.817	8	0.816	0/1	0	1	1
882	0	11800	2	0.464	4	0.464	0/1	0	0	1
82	0	12942	2	0.423	4	0.423	0/1	0	0	1
751	0	6891	2	0.795	2	0.795	0/1	0	1	1
983	0	10657	1	0.257	3	0.257	0/1	0	0	1
388	0	8722	0	0.000	1	0.000	0/1	0	0	1
2	0	12715	0	0.000	1	0.000	0/1	0	1	1
600	0	15973	7	1.201	8	1.201	0/1	0	1	1
938	0	10070	2	0.544	2	0.544	0/1	0	1	1
97	0	13649	8	1.606	9	1.606	0/1	0	1	1
989	1	12981	2	0.422	4	0.422	1	0	0	1

810	1	12798	0	0.000	0	0.000	1	0	0	1
900	1	14832	4	0.739	5	0.739	1	0	0	1
902	1	8678	1	0.316	1	0.316	1	0	0	1
5	1	12927	1	0.212	1	0.212	1	0	0	1
68	1	16543	3	0.497	3	0.497	1	0	1	1
920	1	13198	0	0.000	0	0.000	1	0	0	1
162	1	15322	4	0.715	7	0.715	1	0	0	1
342	1	18622	5	0.736	7	0.736	1	1	0	1
895	1	15735	1	0.174	3	0.174	1	0	1	1
832	1	11778	2	0.465	2	0.465	1	0	0	0
966	1	14283	9	1.726	10	1.726	1	0	1	1
482	1	20475	8	1.071	8	1.070	1	0	1	1
882	1	12000	1	0.228	2	0.228	1	0	0	1
82	1	13162	1	0.208	2	0.208	1	0	0	1
751	1	7007	1	0.391	2	0.391	1	0	1	1
983	1	10838	1	0.253	1	0.253	1	0	0	1
388	1	8870	0	0.000	2	0.000	1	0	0	1
2	1	12930	1	0.212	2	0.212	1	0	1	1
600	1	16244	2	0.337	4	0.337	1	0	1	1
938	1	10241	0	0.000	4	0.000	1	0	1	1
97	1	13880	2	0.395	2	0.395	1	0	1	1
989	2	13201	4	0.830	7	0.830	1	0	0	1
810	2	13015	0	0.000	0	0.000	1	0	0	1
900	2	15084	5	0.908	5	0.908	1	0	0	1
902	2	8825	1	0.310	1	0.310	1	0	0	1
5	2	13146	0	0.000	0	0.000	1	0	0	1
68	2	16823	2	0.326	3	0.326	1	0	1	1
920	2	13422	4	0.817	10	0.816	1	0	0	1
162	2	15582	3	0.528	11	0.527	1	0	0	1
342	2	18938	2	0.289	8	0.289	1	1	0	1
895	2	16002	1	0.171	2	0.171	1	0	1	1
832	2	11978	2	0.458	3	0.457	1	0	0	0
966	2	14525	8	1.509	10	1.509	1	0	1	1
482	2	20822	6	0.790	10	0.789	1	0	1	1
882	2	12204	3	0.674	4	0.673	1	0	0	1
82	2	13385	2	0.409	4	0.409	1	0	0	1
751	2	7126	2	0.769	4	0.769	1	0	1	1
983	2	11022	1	0.249	1	0.249	1	0	0	1
388	2	9020	0	0.000	3	0.000	1	0	0	1
2	2	13150	1	0.208	2	0.208	1	0	1	1
600	2	16519	5	0.829	9	0.829	1	0	1	1
938	2	10414	1	0.263	1	0.263	1	0	1	1
97	2	14116	2	0.388	3	0.388	1	0	1	1
989	3	13426	1	0.204	5	0.204	1	0	0	1
810	3	13236	0	0.000	0	0.000	1	0	0	1
900	3	15340	9	1.607	9	1.607	1	0	0	1

902	3	8975	0	0.000	0	0.000	1	0	0	1
5	3	13369	0	0.000	0	0.000	1	0	0	1
68	3	17109	2	0.320	5	0.320	1	0	1	1
920	3	13650	1	0.201	2	0.201	1	0	0	1
162	3	15847	8	1.383	12	1.383	1	0	0	1
342	3	19259	5	0.711	8	0.711	1	1	0	1
895	3	16274	12	2.020	1	2.020	1	0	1	1
832	3	12181	2	0.450	2	0.450	1	0	0	0
966	3	14771	6	1.113	8	1.113	1	0	1	1
482	3	21176	12	1.553	15	1.553	1	0	1	1
882	3	12411	2	0.442	3	0.441	1	0	0	1
82	3	13612	1	0.201	5	0.201	1	0	0	1
751	3	7247	1	0.378	5	0.378	1	0	1	1
983	3	11209	0	0.000	0	0.000	1	0	0	1
388	3	9173	1	0.299	2	0.299	1	0	0	1
2	3	13373	2	0.410	2	0.410	1	0	1	1
600	3	16800	3	0.489	4	0.489	1	0	1	1
938	3	10591	1	0.259	1	0.259	1	0	1	1
97	3	14355	9	1.718	9	1.718	1	0	1	1
989	4	13653	0	0.000	4	0.000	1	0	0	1
810	4	13461	2	0.407	2	0.407	1	0	0	1
900	4	15600	4	0.703	4	0.702	1	0	0	1
902	4	9127	1	0.300	1	0.300	1	0	0	1
5	4	13596	1	0.202	1	0.202	1	0	0	1
68	4	17399	2	0.315	3	0.315	1	0	1	1
920	4	13881	4	0.790	6	0.789	1	0	0	1
162	4	16116	5	0.850	10	0.850	1	0	0	1
342	4	19586	4	0.560	5	0.560	1	1	0	1
895	4	16550	2	0.331	3	0.331	1	0	1	1
832	4	12387	3	0.664	4	0.664	1	0	0	0
966	4	15022	8	1.459	11	1.459	1	0	1	1
482	4	21535	6	0.763	8	0.763	1	0	1	1
882	4	12621	2	0.434	2	0.434	1	0	0	1
82	4	13843	2	0.396	3	0.396	1	0	0	1
751	4	7370	2	0.743	5	0.743	1	0	1	1
983	4	11399	0	0.000	0	0.000	1	0	0	1
388	4	9329	0	0.000	5	0.000	1	0	0	1
2	4	13600	1	0.202	2	0.201	1	0	1	1
600	4	17085	3	0.481	4	0.481	1	0	1	1
938	4	10771	3	0.763	5	0.763	1	0	1	1
97	4	14599	4	0.751	5	0.751	1	0	1	1
989	5	13885	3	0.197	3	0.592	1	0	0	1
810	5	13689	2	0.200	2	0.400	1	0	0	1
900	5	15865	5	0.864	5	0.863	1	0	0	1
902	5	9282	1	0.295	1	0.295	1	0	0	1
5	5	13827	0	0.000	0	0.000	1	0	0	1

68	5	17694	3	0.465	3	0.465	1	0	1	1
920	5	14117	3	0.194	3	0.582	1	0	0	1
162	5	16389	17	1.337	17	2.842	1	0	0	1
342	5	19918	8	0.825	8	1.100	1	1	0	1
895	5	16831	5	0.814	5	0.814	1	0	1	1
832	5	12598	4	0.652	4	0.870	1	0	0	0
966	5	15277	9	1.435	9	1.614	1	0	1	1
482	5	21900	15	1.501	15	1.877	1	0	1	1
882	5	12835	3	0.427	3	0.640	1	0	0	1
82	5	14078	2	0.389	2	0.389	1	0	0	1
751	5	7495	6	0.000	6	2.193	1	0	1	1
983	5	11593	0	0.000	0	0.000	1	0	0	1
388	5	9487	2	0.000	2	0.578	1	0	0	1
2	5	13831	2	0.198	2	0.396	1	0	1	1
600	5	17375	4	0.473	4	0.631	1	0	1	1
938	5	10954	5	0.500	5	1.251	1	0	1	1
97	5	14847	4	0.369	4	0.738	1	0	1	1
981	-5	6482	0	0.000	1	0.423	0	0	0	1
975	-5	7554	0	0.000	1	0.363	0	0	0	0
970	-5	8164	1	0.336	1	0.336	0	0	0	0
942	-5	3111	1	0.881	1	0.881	0	0	0	0
919	-5	5062	2	1.082	2	1.082	0	0	0	1
870	-5	3857	0	0.000	0	0.000	0	0	1	1
841	-5	18481	6	0.889	9	1.334	0	0	0	1
837	-5	13767	1	0.199	4	0.796	0	0	0	1
797	-5	13932	7	1.377	11	2.163	0	1	0	1
791	-5	13178	0	0.000	0	0.000	0	0	0	1
577	-5	10956	2	0.500	2	0.500	0	0	1	1
499	-5	16430	4	0.667	8	1.334	0	0	1	1
497	-5	8999	4	1.218	4	1.218	0	0	0	1
490	-5	6468	2	0.847	5	2.118	0	0	0	1
469	-5	8598	1	0.319	2	0.637	0	0	1	1
468	-5	10004	0	0.000	0	0.000	0	0	1	1
463	-5	13459	2	0.407	4	0.814	0	0	1	1
389	-5	4090	0	0.000	0	0.000	0	0	0	1
368	-5	12631	1	0.217	1	0.217	0	0	1	1
361	-5	7714	2	0.710	4	1.421	0	0	0	1
345	-5	9240	2	0.593	4	1.186	0	0	1	1
339	-5	23044	1	0.119	1	0.119	0	1	0	1
299	-5	1782	1	1.537	2	3.075	0	0	0	0
268	-5	20756	0	0.000	0	0.000	0	1	0	1
267	-5	13137	0	0.000	0	0.000	0	0	0	1
231	-5	13325	2	0.411	2	0.411	0	0	1	1
227	-5	6428	4	1.705	4	1.705	0	0	0	1
203	-5	25311	6	0.649	9	0.974	0	1	0	1
177	-5	12917	1	0.212	1	0.212	0	0	1	1

176	-5	7477	4	1.466	4	1.466	0	0	1	1
150	-5	8236	1	0.333	3	0.998	0	0	0	1
116	-5	10526	2	0.521	2	0.521	0	0	1	1
112	-5	4741	0	0.000	2	1.156	0	0	0	1
74	-5	16352	3	0.503	6	1.005	0	0	0	1
52	-5	14905	3	0.551	4	0.735	0	0	0	1
34	-5	12213	3	0.673	3	0.673	0	0	1	1
28	-5	9067	1	0.302	4	1.209	0	0	0	1
26	-5	13338	1	0.205	2	0.411	0	0	1	1
115	-5	12615	3	0.652	5	1.086	0	0	1	1
261	-5	15829	6	1.039	10	1.731	0	0	1	1
872	-5	11785	2	0.465	3	0.697	0	0	0	1
9	-5	9562	0	0.000	0	0.000	0	0	0	1
892	-5	8839	0	0.000	0	0.000	0	0	0	0
598	-5	10365	4	1.057	4	1.057	0	0	0	1
736	-5	18917	1	0.145	2	0.290	0	0	1	1
17	-5	10868	4	1.008	7	1.765	0	0	1	1
356	-5	9723	3	0.845	5	1.409	0	0	0	1
981	-4	6592	1	0.416	1	0.416	0	0	0	1
975	-4	7682	1	0.357	2	0.713	0	0	0	0
970	-4	8302	0	0.000	0	0.000	0	0	0	0
942	-4	3164	0	0.000	1	0.866	0	0	0	0
919	-4	5148	0	0.000	2	1.064	0	0	0	1
870	-4	3922	1	0.699	1	0.699	0	0	1	1
841	-4	18794	6	0.875	8	1.166	0	0	0	1
837	-4	14000	0	0.000	3	0.587	0	0	0	1
797	-4	14169	6	1.160	10	1.934	0	1	0	1
791	-4	13401	0	0.000	1	0.204	0	0	0	1
577	-4	11141	4	0.984	4	0.984	0	0	1	1
499	-4	16709	3	0.492	4	0.656	0	0	1	1
497	-4	9152	1	0.299	2	0.599	0	0	0	1
490	-4	6578	2	0.833	2	0.833	0	0	0	1
469	-4	8744	2	0.627	2	0.627	0	0	1	1
468	-4	10174	3	0.808	4	1.077	0	0	1	1
463	-4	13687	2	0.400	3	0.601	0	0	1	1
389	-4	4160	1	0.659	1	0.659	0	0	0	1
368	-4	12845	1	0.213	1	0.213	0	0	1	1
361	-4	7845	1	0.349	4	1.397	0	0	0	1
345	-4	9396	0	0.000	1	0.292	0	0	1	1
339	-4	23435	1	0.117	2	0.234	0	1	0	1
299	-4	1812	0	0.000	0	0.000	0	0	0	0
268	-4	21108	0	0.000	0	0.000	0	1	0	1
267	-4	13360	3	0.615	3	0.615	0	0	0	1
231	-4	13551	1	0.202	2	0.404	0	0	1	1
227	-4	6537	0	0.000	0	0.000	0	0	0	1
203	-4	25740	9	0.958	11	1.171	0	1	0	1

177	-4	13136	2	0.417	2	0.417	0	0	1	1
176	-4	7604	4	1.441	4	1.441	0	0	1	1
150	-4	8376	1	0.327	2	0.654	0	0	0	1
116	-4	10705	3	0.768	3	0.768	0	0	1	1
112	-4	4821	2	1.137	2	1.137	0	0	0	1
74	-4	16629	2	0.330	4	0.659	0	0	0	1
52	-4	15158	2	0.361	5	0.904	0	0	0	1
34	-4	12421	3	0.662	5	1.103	0	0	1	1
28	-4	9221	5	1.486	6	1.783	0	0	0	1
26	-4	13565	0	0.000	1	0.202	0	0	1	1
115	-4	12829	4	0.854	9	1.922	0	0	1	1
261	-4	16098	8	1.362	12	2.042	0	0	1	1
872	-4	11985	1	0.229	2	0.457	0	0	0	1
9	-4	9724	2	0.564	3	0.845	0	0	0	1
892	-4	8989	1	0.305	1	0.305	0	0	0	0
598	-4	10541	1	0.260	1	0.260	0	0	0	1
736	-4	19238	1	0.142	4	0.570	0	0	1	1
17	-4	11053	3	0.744	5	1.239	0	0	1	1
356	-4	9888	1	0.277	3	0.831	0	0	0	1
981	-3	6704	2	0.817	6	2.452	0	0	0	1
975	-3	7812	1	0.351	1	0.351	0	0	0	0
970	-3	8443	0	0.000	0	0.000	0	0	0	0
942	-3	3217	0	0.000	2	1.703	0	0	0	0
919	-3	5235	1	0.523	1	0.523	0	0	0	1
870	-3	3989	0	0.000	0	0.000	0	0	1	1
841	-3	19113	3	0.430	8	1.147	0	0	0	1
837	-3	14238	2	0.385	4	0.770	0	0	0	1
797	-3	14409	7	1.331	12	2.282	0	1	0	1
791	-3	13629	0	0.000	1	0.201	0	0	0	1
577	-3	11331	1	0.242	1	0.242	0	0	1	1
499	-3	16993	6	0.967	9	1.451	0	0	1	1
497	-3	9307	0	0.000	0	0.000	0	0	0	1
490	-3	6690	1	0.410	2	0.819	0	0	0	1
469	-3	8892	2	0.616	5	1.541	0	0	1	1
468	-3	10346	5	1.324	6	1.589	0	0	1	1
463	-3	13920	4	0.787	6	1.181	0	0	1	1
389	-3	4230	0	0.000	2	1.295	0	0	0	1
368	-3	13063	1	0.210	1	0.210	0	0	1	1
361	-3	7978	1	0.343	2	0.687	0	0	0	1
345	-3	9556	0	0.000	1	0.287	0	0	1	1
339	-3	23832	1	0.115	1	0.115	0	1	0	1
299	-3	1843	0	0.000	2	2.973	0	0	0	0
268	-3	21466	0	0.000	0	0.000	0	1	0	1
267	-3	13587	1	0.202	1	0.202	0	0	0	1
231	-3	13781	1	0.199	3	0.596	0	0	1	1
227	-3	6648	3	1.236	3	1.236	0	0	0	1

203	-3	26177	9	0.942	9	0.942	0	1	0	1
177	-3	13359	1	0.205	1	0.205	0	0	1	1
176	-3	7733	2	0.709	4	1.417	0	0	1	1
150	-3	8518	1	0.322	2	0.643	0	0	0	1
116	-3	10886	0	0.000	2	0.503	0	0	1	1
112	-3	4903	0	0.000	0	0.000	0	0	0	1
74	-3	16911	3	0.486	4	0.648	0	0	0	1
52	-3	15415	3	0.533	4	0.711	0	0	0	1
34	-3	12631	7	1.518	8	1.735	0	0	1	1
28	-3	9377	1	0.292	2	0.584	0	0	0	1
26	-3	13795	0	0.000	1	0.199	0	0	1	1
115	-3	13047	1	0.210	3	0.630	0	0	1	1
261	-3	16371	1	0.167	2	0.335	0	0	1	1
872	-3	12189	0	0.000	0	0.000	0	0	0	1
9	-3	9889	2	0.554	2	0.554	0	0	0	1
892	-3	9141	4	1.199	4	1.199	0	0	0	0
598	-3	10720	3	0.767	3	0.767	0	0	0	1
736	-3	19565	0	0.000	2	0.280	0	0	1	1
17	-3	11240	4	0.975	5	1.219	0	0	1	1
356	-3	10055	2	0.545	4	1.090	0	0	0	1
981	-2	6818	0	0.000	1	0.402	0	0	0	1
975	-2	7945	0	0.000	0	0.000	0	0	0	0
970	-2	8586	0	0.000	0	0.000	0	0	0	0
942	-2	3272	1	0.837	3	2.512	0	0	0	0
919	-2	5324	0	0.000	1	0.515	0	0	0	1
870	-2	4057	0	0.000	0	0.000	0	0	1	1
841	-2	19438	2	0.282	6	0.846	0	0	0	1
837	-2	14479	1	0.189	1	0.189	0	0	0	1
797	-2	14654	9	1.683	12	2.244	0	1	0	1
791	-2	13860	1	0.198	2	0.395	0	0	0	1
577	-2	11523	2	0.476	3	0.713	0	0	1	1
499	-2	17281	6	0.951	11	1.744	0	0	1	1
497	-2	9465	1	0.289	1	0.289	0	0	0	1
490	-2	6803	2	0.805	2	0.805	0	0	0	1
469	-2	9043	2	0.606	3	0.909	0	0	1	1
468	-2	10522	4	1.042	6	1.562	0	0	1	1
463	-2	14156	0	0.000	0	0.000	0	0	1	1
389	-2	4302	1	0.637	2	1.274	0	0	0	1
368	-2	13285	4	0.825	4	0.825	0	0	1	1
361	-2	8113	3	1.013	3	1.013	0	0	0	1
345	-2	9718	1	0.282	2	0.564	0	0	1	1
339	-2	24237	0	0.000	0	0.000	0	1	0	1
299	-2	1874	0	0.000	0	0.000	0	0	0	0
268	-2	21830	2	0.251	2	0.251	0	1	0	1
267	-2	13818	1	0.198	1	0.198	0	0	0	1
231	-2	14015	1	0.195	2	0.391	0	0	1	1

227	-2	6761	2	0.810	2	0.810	0	0	0	1
203	-2	26621	6	0.618	7	0.720	0	1	0	1
177	-2	13586	2	0.403	4	0.807	0	0	1	1
176	-2	7864	2	0.697	2	0.697	0	0	1	1
150	-2	8662	1	0.316	1	0.316	0	0	0	1
116	-2	11071	2	0.495	3	0.742	0	0	1	1
112	-2	4986	0	0.000	1	0.549	0	0	0	1
74	-2	17198	1	0.159	1	0.159	0	0	0	1
52	-2	15677	4	0.699	7	1.223	0	0	0	1
34	-2	12846	0	0.000	2	0.427	0	0	1	1
28	-2	9537	1	0.287	4	1.149	0	0	0	1
26	-2	14029	4	0.781	6	1.172	0	0	1	1
115	-2	13268	5	1.032	7	1.445	0	0	1	1
261	-2	16649	8	1.316	10	1.646	0	0	1	1
872	-2	12396	4	0.884	4	0.884	0	0	0	1
9	-2	10057	0	0.000	0	0.000	0	0	0	1
892	-2	9296	2	0.589	4	1.179	0	0	0	0
598	-2	10902	2	0.503	2	0.503	0	0	0	1
736	-2	19897	1	0.138	2	0.275	0	0	1	1
17	-2	11431	2	0.479	2	0.479	0	0	1	1
356	-2	10226	2	0.536	3	0.804	0	0	0	1
981	-1	6934	1	0.395	2	0.790	0	0	0	1
975	-1	8080	0	0.000	0	0.000	0	0	0	0
970	-1	8732	0	0.000	0	0.000	0	0	0	0
942	-1	3327	2	1.647	2	1.647	0	0	0	0
919	-1	5415	0	0.000	1	0.506	0	0	0	1
870	-1	4125	2	1.328	5	3.321	0	0	1	1
841	-1	19768	8	1.109	8	1.109	0	0	0	1
837	-1	14725	0	0.000	1	0.186	0	0	0	1
797	-1	14903	8	1.471	13	2.390	0	1	0	1
791	-1	14095	0	0.000	1	0.194	0	0	0	1
577	-1	11718	0	0.000	1	0.234	0	0	1	1
499	-1	17574	1	0.156	3	0.468	0	0	1	1
497	-1	9626	1	0.285	3	0.854	0	0	0	1
490	-1	6919	2	0.792	4	1.584	0	0	0	1
469	-1	9196	0	0.000	2	0.596	0	0	1	1
468	-1	10700	4	1.024	4	1.024	0	0	1	1
463	-1	14396	1	0.190	1	0.190	0	0	1	1
389	-1	4375	1	0.626	4	2.505	0	0	0	1
368	-1	13510	2	0.406	2	0.406	0	0	1	1
361	-1	8251	3	0.996	5	1.660	0	0	0	1
345	-1	9883	2	0.554	2	0.554	0	0	1	1
339	-1	24648	1	0.111	1	0.111	0	1	0	1
299	-1	1906	0	0.000	0	0.000	0	0	0	0
268	-1	22201	2	0.247	2	0.247	0	1	0	1
267	-1	14052	1	0.195	2	0.390	0	0	0	1

231	-1	14253	1	0.192	1	0.192	0	0	1	1
227	-1	6876	4	1.594	6	2.391	0	0	0	1
203	-1	27073	12	1.214	15	1.518	0	1	0	1
177	-1	13816	1	0.198	1	0.198	0	0	1	1
176	-1	7998	6	2.055	7	2.398	0	0	1	1
150	-1	8809	2	0.622	2	0.622	0	0	0	1
116	-1	11259	3	0.730	5	1.217	0	0	1	1
112	-1	5071	0	0.000	1	0.540	0	0	0	1
74	-1	17490	0	0.000	0	0.000	0	0	0	1
52	-1	15943	1	0.172	3	0.516	0	0	0	1
34	-1	13064	5	1.049	7	1.468	0	0	1	1
28	-1	9698	3	0.848	6	1.695	0	0	0	1
26	-1	14267	1	0.192	2	0.384	0	0	1	1
115	-1	13494	3	0.609	4	0.812	0	0	1	1
261	-1	16931	2	0.324	7	1.133	0	0	1	1
872	-1	12606	1	0.217	1	0.217	0	0	0	1
9	-1	10228	0	0.000	1	0.268	0	0	0	1
892	-1	9454	3	0.869	6	1.739	0	0	0	0
598	-1	11087	3	0.741	3	0.741	0	0	0	1
736	-1	20234	2	0.271	2	0.271	0	0	1	1
17	-1	11625	2	0.471	3	0.707	0	0	1	1
356	-1	10399	4	1.054	6	1.581	0	0	0	1
981	0	7051	1	0.389	2	0.777	0	0	0	1
975	0	8217	1	0.333	2	0.667	0	0	0	0
970	0	8880	0	0.000	0	0.000	0	0	0	0
942	0	3384	0	0.000	1	0.810	0	0	0	0
919	0	5506	0	0.000	0	0.000	0	0	0	1
870	0	4195	4	2.612	7	4.572	0	0	1	1
841	0	20103	4	0.545	8	1.090	0	0	0	1
837	0	14975	2	0.366	4	0.732	0	0	0	1
797	0	15155	9	1.627	12	2.169	0	1	0	1
791	0	14334	3	0.573	3	0.573	0	0	0	1
577	0	11917	2	0.460	2	0.460	0	0	1	1
499	0	17873	5	0.766	6	0.920	0	0	1	1
497	0	9789	2	0.560	4	1.120	0	0	0	1
490	0	7036	1	0.389	1	0.389	0	0	0	1
469	0	9352	2	0.586	2	0.586	0	0	1	1
468	0	10882	3	0.755	6	1.511	0	0	1	1
463	0	14640	1	0.187	2	0.374	0	0	1	1
389	0	4449	1	0.616	1	0.616	0	0	0	1
368	0	13739	2	0.399	3	0.598	0	0	1	1
361	0	8391	2	0.653	2	0.653	0	0	0	1
345	0	10051	2	0.545	2	0.545	0	0	1	1
339	0	25066	2	0.219	2	0.219	0	1	0	1
299	0	1938	0	0.000	1	1.414	0	0	0	0
268	0	22578	3	0.364	3	0.364	0	1	0	1

267	0	14291	0	0.000	3	0.575	0	0	0	1
231	0	14495	0	0.000	2	0.378	0	0	1	1
227	0	6992	1	0.392	1	0.392	0	0	0	1
203	0	27532	13	1.294	15	1.493	0	1	0	1
177	0	14051	3	0.585	3	0.585	0	0	1	1
176	0	8133	1	0.337	2	0.674	0	0	1	1
150	0	8959	2	0.612	2	0.612	0	0	0	1
116	0	11450	1	0.239	1	0.239	0	0	1	1
112	0	5157	0	0.000	1	0.531	0	0	0	1
74	0	17787	2	0.308	3	0.462	0	0	0	1
52	0	16214	2	0.338	5	0.845	0	0	0	1
34	0	13286	2	0.412	3	0.619	0	0	1	1
28	0	9863	1	0.278	1	0.278	0	0	0	1
26	0	14509	2	0.378	4	0.755	0	0	1	1
115	0	13723	6	1.198	11	2.196	0	0	1	1
261	0	17219	0	0.000	1	0.159	0	0	1	1
872	0	12820	0	0.000	1	0.214	0	0	0	1
9	0	10401	1	0.263	1	0.263	0	0	0	1
892	0	9615	2	0.570	4	1.140	0	0	0	0
598	0	11275	2	0.486	2	0.486	0	0	0	1
736	0	20578	4	0.533	6	0.799	0	0	1	1
17	0	11822	2	0.464	3	0.695	0	0	1	1
356	0	10576	3	0.777	3	0.777	0	0	0	1
981	1	7171	0	0.000	1	0.382	0	0	0	1
975	1	8356	1	0.328	1	0.328	0	0	0	0
970	1	9031	0	0.000	0	0.000	0	0	0	0
942	1	3441	0	0.000	0	0.000	0	0	0	0
919	1	5600	0	0.000	1	0.489	0	0	0	1
870	1	4267	2	1.284	6	3.852	0	0	1	1
841	1	20444	8	1.072	10	1.340	0	0	0	1
837	1	15229	1	0.180	5	0.900	0	0	0	1
797	1	15413	11	1.955	17	3.022	0	1	0	1
791	1	14578	2	0.376	2	0.376	0	0	0	1
577	1	12119	2	0.452	3	0.678	0	0	1	1
499	1	18176	6	0.904	10	1.507	0	0	1	1
497	1	9955	2	0.550	4	1.101	0	0	0	1
490	1	7155	1	0.383	1	0.383	0	0	0	1
469	1	9511	2	0.576	3	0.864	0	0	1	1
468	1	11067	3	0.743	3	0.743	0	0	1	1
463	1	14889	2	0.368	3	0.552	0	0	1	1
389	1	4525	1	0.605	3	1.816	0	0	0	1
368	1	13972	0	0.000	0	0.000	0	0	1	1
361	1	8533	1	0.321	1	0.321	0	0	0	1
345	1	10221	3	0.804	3	0.804	0	0	1	1
339	1	25492	2	0.215	3	0.322	0	1	0	1
299	1	1971	0	0.000	1	1.390	0	0	0	0

268	1	22961	1	0.119	1	0.119	0	1	0	1
267	1	14533	2	0.377	2	0.377	0	0	0	1
231	1	14741	0	0.000	1	0.186	0	0	1	1
227	1	7111	3	1.156	4	1.541	0	0	0	1
203	1	28000	5	0.489	7	0.685	0	1	0	1
177	1	14289	2	0.383	4	0.767	0	0	1	1
176	1	8271	1	0.331	1	0.331	0	0	1	1
150	1	9111	1	0.301	1	0.301	0	0	0	1
116	1	11644	3	0.706	5	1.176	0	0	1	1
112	1	5244	0	0.000	0	0.000	0	0	0	1
74	1	18089	1	0.151	5	0.757	0	0	0	1
52	1	16489	2	0.332	4	0.665	0	0	0	1
34	1	13511	0	0.000	0	0.000	0	0	1	1
28	1	10030	2	0.546	2	0.546	0	0	0	1
26	1	14755	1	0.186	1	0.186	0	0	1	1
115	1	13955	4	0.785	5	0.982	0	0	1	1
261	1	17511	4	0.626	10	1.565	0	0	1	1
872	1	13037	2	0.420	2	0.420	0	0	0	1
9	1	10578	2	0.518	2	0.518	0	0	0	1
892	1	9778	3	0.841	4	1.121	0	0	0	0
598	1	11467	3	0.717	3	0.717	0	0	0	1
736	1	20927	4	0.524	4	0.524	0	0	1	1
17	1	12023	2	0.456	3	0.684	0	0	1	1
356	1	10755	1	0.255	2	0.509	0	0	0	1
981	2	7293	4	1.503	4	1.503	0	0	0	1
975	2	8498	1	0.322	2	0.645	0	0	0	0
970	2	9184	0	0.000	0	0.000	0	0	0	0
942	2	3500	0	0.000	0	0.000	0	0	0	0
919	2	5695	1	0.481	2	0.962	0	0	0	1
870	2	4339	0	0.000	1	0.631	0	0	1	1
841	2	20791	6	0.791	8	1.054	0	0	0	1
837	2	15488	1	0.177	2	0.354	0	0	0	1
797	2	15674	3	0.524	6	1.049	0	1	0	1
791	2	14825	0	0.000	1	0.185	0	0	0	1
577	2	12325	0	0.000	2	0.445	0	0	1	1
499	2	18484	13	1.927	14	2.075	0	0	1	1
497	2	10124	1	0.271	2	0.541	0	0	0	1
490	2	7277	2	0.753	2	0.753	0	0	0	1
469	2	9672	1	0.283	3	0.850	0	0	1	1
468	2	11254	4	0.974	5	1.217	0	0	1	1
463	2	15141	4	0.724	4	0.724	0	0	1	1
389	2	4602	0	0.000	2	1.191	0	0	0	1
368	2	14209	1	0.193	1	0.193	0	0	1	1
361	2	8678	0	0.000	3	0.947	0	0	0	1
345	2	10395	2	0.527	2	0.527	0	0	1	1
339	2	25924	2	0.211	2	0.211	0	1	0	1

299	2	2004	0	0.000	0	0.000	0	0	0	0
268	2	23350	0	0.000	1	0.117	0	1	0	1
267	2	14780	2	0.371	2	0.371	0	0	0	1
231	2	14991	0	0.000	1	0.183	0	0	1	1
227	2	7232	2	0.758	3	1.137	0	0	0	1
203	2	28475	10	0.962	14	1.347	0	1	0	1
177	2	14531	3	0.566	4	0.754	0	0	1	1
176	2	8412	2	0.651	3	0.977	0	0	1	1
150	2	9266	0	0.000	3	0.887	0	0	0	1
116	2	11842	2	0.463	2	0.463	0	0	1	1
112	2	5333	0	0.000	0	0.000	0	0	0	1
74	2	18396	2	0.298	4	0.596	0	0	0	1
52	2	16769	2	0.327	3	0.490	0	0	0	1
34	2	13740	1	0.199	2	0.399	0	0	1	1
28	2	10201	1	0.269	4	1.074	0	0	0	1
26	2	15006	1	0.183	1	0.183	0	0	1	1
115	2	14192	4	0.772	10	1.930	0	0	1	1
261	2	17808	1	0.154	7	1.077	0	0	1	1
872	2	13259	0	0.000	0	0.000	0	0	0	1
9	2	10757	3	0.764	3	0.764	0	0	0	1
892	2	9944	3	0.827	5	1.378	0	0	0	0
598	2	11661	2	0.470	3	0.705	0	0	0	1
736	2	21282	4	0.515	6	0.772	0	0	1	1
17	2	12227	5	1.120	6	1.344	0	0	1	1
356	2	10938	3	0.751	4	1.002	0	0	0	1
981	3	7416	3	1.108	4	1.478	0	0	0	1
975	3	8642	0	0.000	0	0.000	0	0	0	0
970	3	9340	0	0.000	1	0.293	0	0	0	0
942	3	3559	1	0.770	1	0.770	0	0	0	0
919	3	5792	2	0.946	2	0.946	0	0	0	1
870	3	4413	0	0.000	3	1.862	0	0	1	1
841	3	21144	4	0.518	12	1.555	0	0	0	1
837	3	15750	0	0.000	2	0.348	0	0	0	1
797	3	15940	5	0.859	10	1.719	0	1	0	1
791	3	15077	1	0.182	1	0.182	0	0	0	1
577	3	12534	1	0.219	2	0.437	0	0	1	1
499	3	18798	6	0.874	8	1.166	0	0	1	1
497	3	10296	3	0.798	6	1.597	0	0	0	1
490	3	7400	2	0.740	2	0.740	0	0	0	1
469	3	9837	0	0.000	0	0.000	0	0	1	1
468	3	11445	1	0.239	3	0.718	0	0	1	1
463	3	15398	0	0.000	3	0.534	0	0	1	1
389	3	4680	0	0.000	1	0.585	0	0	0	1
368	3	14451	1	0.190	1	0.190	0	0	1	1
361	3	8825	0	0.000	2	0.621	0	0	0	1
345	3	10571	2	0.518	3	0.778	0	0	1	1

339	3	26364	3	0.312	3	0.312	0	1	0	1
299	3	2038	0	0.000	0	0.000	0	0	0	0
268	3	23747	5	0.577	5	0.577	0	1	0	1
267	3	15031	1	0.182	2	0.365	0	0	0	1
231	3	15245	1	0.180	2	0.359	0	0	1	1
227	3	7354	6	2.235	8	2.980	0	0	0	1
203	3	28958	13	1.230	15	1.419	0	1	0	1
177	3	14778	1	0.185	1	0.185	0	0	1	1
176	3	8554	1	0.320	1	0.320	0	0	1	1
150	3	9423	0	0.000	1	0.291	0	0	0	1
116	3	12043	2	0.455	2	0.455	0	0	1	1
112	3	5424	1	0.505	1	0.505	0	0	0	1
74	3	18708	0	0.000	3	0.439	0	0	0	1
52	3	17053	2	0.321	2	0.321	0	0	0	1
34	3	13973	1	0.196	1	0.196	0	0	1	1
28	3	10374	0	0.000	2	0.528	0	0	0	1
26	3	15260	4	0.718	5	0.898	0	0	1	1
115	3	14433	6	1.139	9	1.708	0	0	1	1
261	3	18110	7	1.059	10	1.513	0	0	1	1
872	3	13484	1	0.203	1	0.203	0	0	0	1
9	3	10940	2	0.501	2	0.501	0	0	0	1
892	3	10112	1	0.271	2	0.542	0	0	0	0
598	3	11859	4	0.924	9	2.079	0	0	0	1
736	3	21643	6	0.760	12	1.519	0	0	1	1
17	3	12434	5	1.102	5	1.102	0	0	1	1
356	3	11124	0	0.000	0	0.000	0	0	0	1
981	4	7542	3	1.090	6	2.180	0	0	0	1
975	4	8789	0	0.000	0	0.000	0	0	0	0
970	4	9499	0	0.000	0	0.000	0	0	0	0
942	4	3620	0	0.000	0	0.000	0	0	0	0
919	4	5890	1	0.465	2	0.930	0	0	0	1
870	4	4488	2	1.221	3	1.831	0	0	1	1
841	4	21503	6	0.764	11	1.402	0	0	0	1
837	4	16018	2	0.342	5	0.855	0	0	0	1
797	4	16211	5	0.845	9	1.521	0	1	0	1
791	4	15332	1	0.179	2	0.357	0	0	0	1
577	4	12747	2	0.430	5	1.075	0	0	1	1
499	4	19117	9	1.290	15	2.150	0	0	1	1
497	4	10471	1	0.262	2	0.523	0	0	0	1
490	4	7526	2	0.728	2	0.728	0	0	0	1
469	4	10003	2	0.548	2	0.548	0	0	1	1
468	4	11640	2	0.471	5	1.177	0	0	1	1
463	4	15660	3	0.525	5	0.875	0	0	1	1
389	4	4759	1	0.576	5	2.878	0	0	0	1
368	4	14696	2	0.373	2	0.373	0	0	1	1
361	4	8975	1	0.305	3	0.916	0	0	0	1

345	4	10750	3	0.765	5	1.274	0	0	1	1
339	4	26812	1	0.102	2	0.204	0	1	0	1
299	4	2073	0	0.000	0	0.000	0	0	0	0
268	4	24150	0	0.000	0	0.000	0	1	0	1
267	4	15286	4	0.717	4	0.717	0	0	0	1
231	4	15504	1	0.177	1	0.177	0	0	1	1
227	4	7479	2	0.733	3	1.099	0	0	0	1
203	4	29450	8	0.744	10	0.930	0	1	0	1
177	4	15029	1	0.182	2	0.365	0	0	1	1
176	4	8700	4	1.260	4	1.260	0	0	1	1
150	4	9583	1	0.286	2	0.572	0	0	0	1
116	4	12247	2	0.447	3	0.671	0	0	1	1
112	4	5516	0	0.000	0	0.000	0	0	0	1
74	4	19025	2	0.288	5	0.720	0	0	0	1
52	4	17342	4	0.632	6	0.948	0	0	0	1
34	4	14211	1	0.193	1	0.193	0	0	1	1
28	4	10550	0	0.000	2	0.519	0	0	0	1
26	4	15519	2	0.353	2	0.353	0	0	1	1
115	4	14678	1	0.187	5	0.933	0	0	1	1
261	4	18418	4	0.595	6	0.893	0	0	1	1
872	4	13713	0	0.000	0	0.000	0	0	0	1
9	4	11125	3	0.739	4	0.985	0	0	0	1
892	4	10284	1	0.266	2	0.533	0	0	0	0
598	4	12060	1	0.227	1	0.227	0	0	0	1
736	4	22010	1	0.124	1	0.124	0	0	1	1
17	4	12645	2	0.433	2	0.433	0	0	1	1
356	4	11312	1	0.242	3	0.727	0	0	0	1
981	5	7670	3	1.072	4	1.429	0	0	0	1
975	5	8938	0	0.000	0	0.000	0	0	0	0
970	5	9660	0	0.000	0	0.000	0	0	0	0
942	5	3681	1	0.744	2	1.489	0	0	0	0
919	5	5990	2	0.915	3	1.372	0	0	0	1
870	5	4564	1	0.600	1	0.600	0	0	1	1
841	5	21868	8	1.002	10	1.253	0	0	0	1
837	5	16290	0	0.000	1	0.168	0	0	0	1
797	5	16486	5	0.831	13	2.160	0	1	0	1
791	5	15593	0	0.000	0	0.000	0	0	0	1
577	5	12963	1	0.211	1	0.211	0	0	1	1
499	5	19442	1	0.141	2	0.282	0	0	1	1
497	5	10649	3	0.772	3	0.772	0	0	0	1
490	5	7654	1	0.358	1	0.358	0	0	0	1
469	5	10173	1	0.269	2	0.539	0	0	1	1
468	5	11837	0	0.000	1	0.231	0	0	1	1
463	5	15925	5	0.860	7	1.204	0	0	1	1
389	5	4840	0	0.000	3	1.698	0	0	0	1
368	5	14945	0	0.000	1	0.183	0	0	1	1

361	5	9127	2	0.600	2	0.600	0	0	0	1
345	5	10933	1	0.251	2	0.501	0	0	1	1
339	5	27267	4	0.402	4	0.402	0	1	0	1
299	5	2108	0	0.000	0	0.000	0	0	0	0
268	5	24559	4	0.446	4	0.446	0	1	0	1
267	5	15545	5	0.881	6	1.057	0	0	0	1
231	5	15767	1	0.174	1	0.174	0	0	1	1
227	5	7606	0	0.000	3	1.081	0	0	0	1
203	5	29949	21	1.921	24	2.196	0	1	0	1
177	5	15284	1	0.179	1	0.179	0	0	1	1
176	5	8847	4	1.239	5	1.548	0	0	1	1
150	5	9745	3	0.843	6	1.687	0	0	0	1
116	5	12455	1	0.220	2	0.440	0	0	1	1
112	5	5610	0	0.000	1	0.488	0	0	0	1
74	5	19348	0	0.000	1	0.142	0	0	0	1
52	5	17637	5	0.777	7	1.087	0	0	0	1
34	5	14452	2	0.379	2	0.379	0	0	1	1
28	5	10729	0	0.000	1	0.255	0	0	0	1
26	5	15783	2	0.347	4	0.694	0	0	1	1
115	5	14927	3	0.551	5	0.918	0	0	1	1
261	5	18730	4	0.585	7	1.024	0	0	1	1
872	5	13945	0	0.000	4	0.786	0	0	0	1
9	5	11314	3	0.726	5	1.211	0	0	0	1
892	5	10458	4	1.048	5	1.310	0	0	0	0
598	5	12265	1	0.223	3	0.670	0	0	0	1
736	5	22384	6	0.734	6	0.734	0	0	1	1
17	5	12860	2	0.426	5	1.065	0	0	1	1
356	5	11504	3	0.714	5	1.191	0	0	0	1

A.4. Relevant Accident Rate Graphs for Treatment Group Intersections

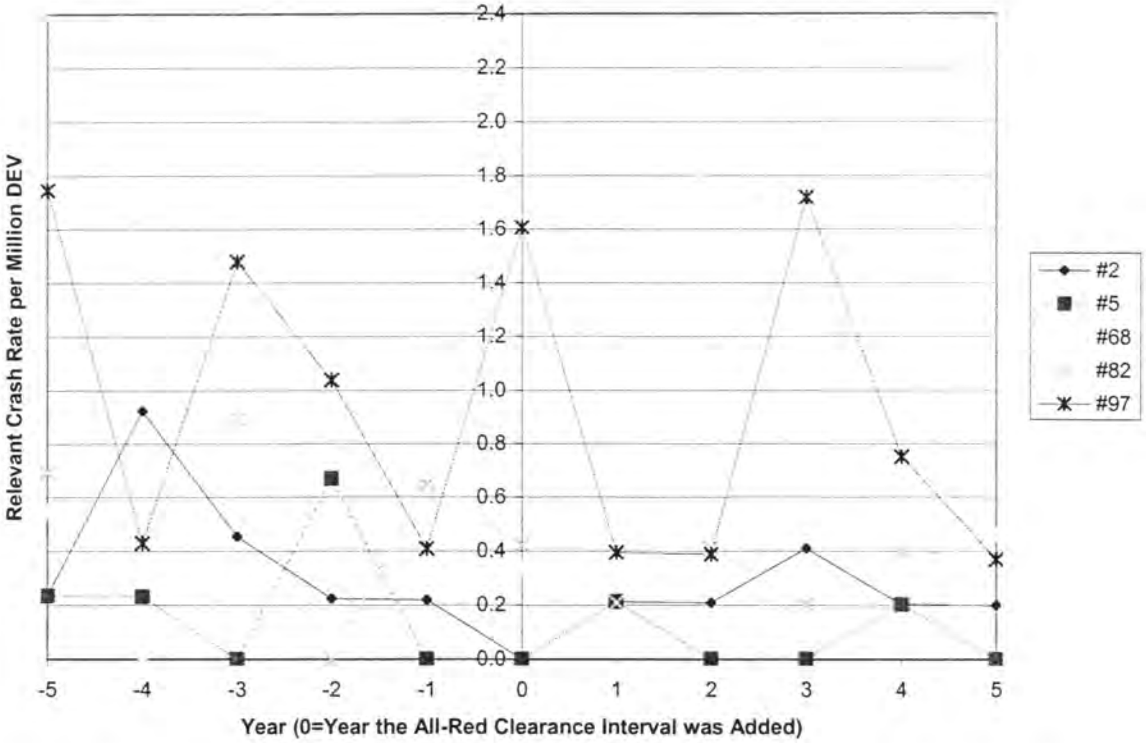


Figure A1: Relevant Accident Rates for Treatment Group Intersections (#2, #5, #68, #82, #97)

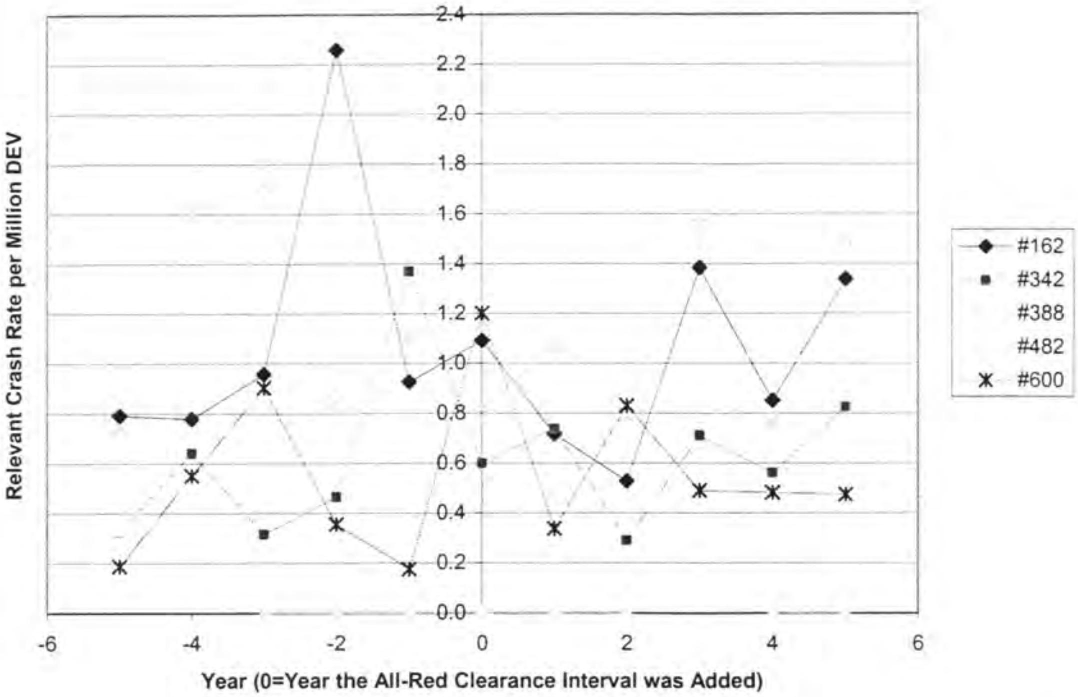


Figure A2: Relevant Accident Rates for Treatment Group Intersections (#162, #342, #388, #482, #600)

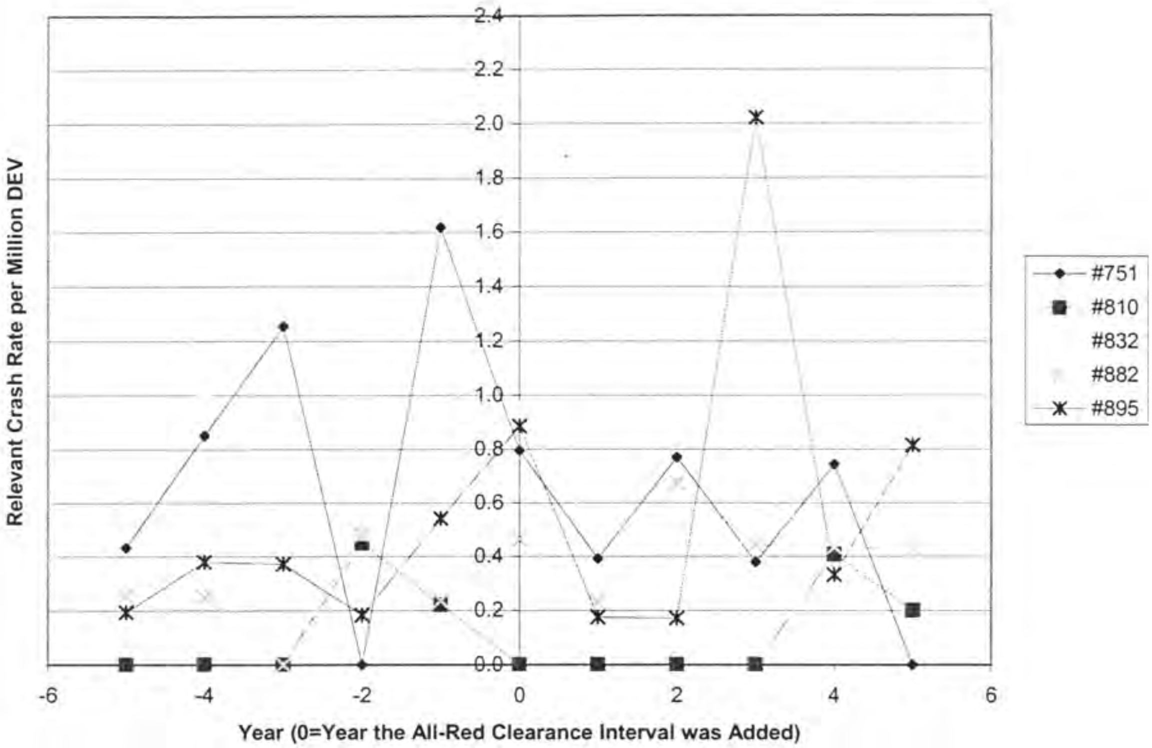


Figure A3: Relevant Accident Rates for Treatment Group Intersections (#751, #810, #832, #882, #895)

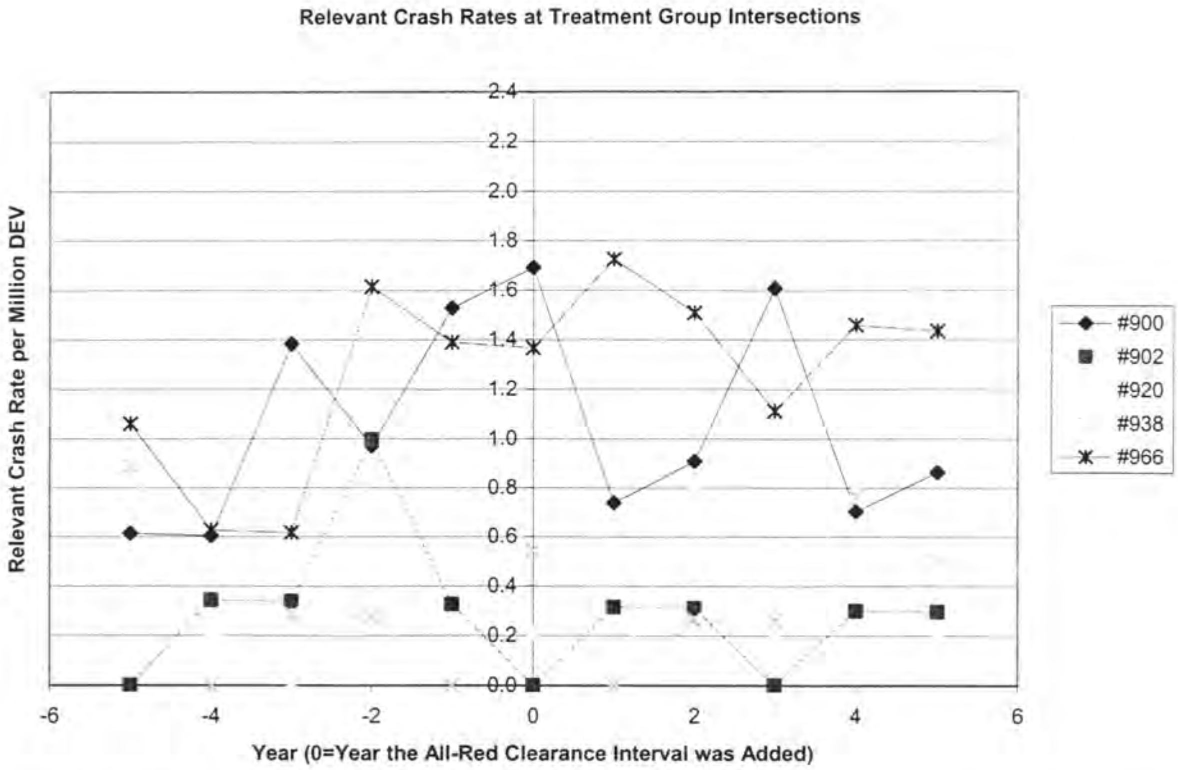


Figure A4: Relevant Accident Rates for Treatment Group Intersections (#900, #902, #920, #938, #966)

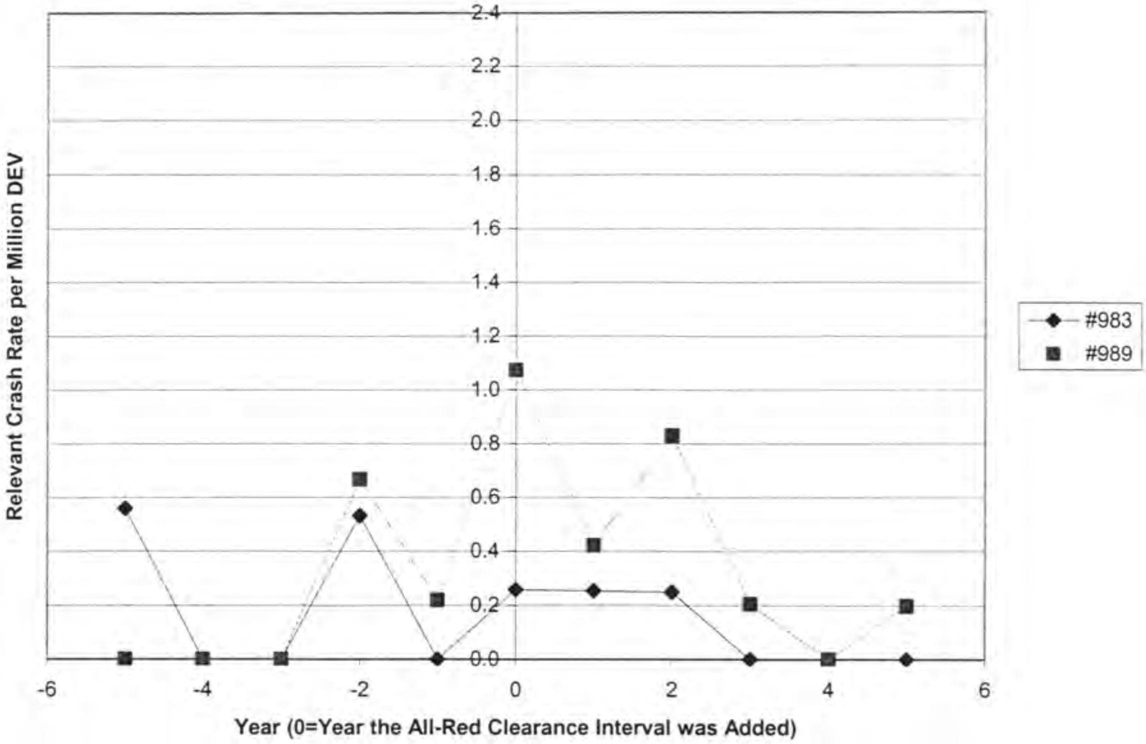


Figure A5: Relevant Accident Rates for Treatment Group Intersections (#983, #989)

Appendix B: Statistical Model Information and Results

B.1. SAS Code

```
PROC IMPORT DATAFILE='D:\06-13 Reid\Molly\X_Sec_Data_with_NUM.xls'
OUT=data0 REPLACE;
RUN;

data DATA1;
 set DATA0;
 MERGER=777;
 run;
*** EXPLORATION OF THE DATA;
*** THE FOLLOWING IS TO EXAMINE SOME BASIC SUMMARY STATISTICS
    OF THE CRASH RATE RESPONSE VARIABLES;
proc sort data=DATA1;
 by TRT;
 run;
proc means mean data=DATA1;
 var DEV;
 ods output summary=out1;
 run;
data out1;
 set out1;
 MERGER=777;
data DATA2;
 merge DATA1 OUT1;
 by MERGER;
 cDEV=DEV-DEV_MEAN;
 SqrtIMP=sqrt(imp_cr);
 SqrtTOT=sqrt(tot_cr);
 drop MERGER;
run;


/***************** START GENERALIZED LINEAR MIXED MODEL SEARCH
**********************/
/*
 MODEL 1: IMP_CR ~ POISSON[Lambda(TRT,D1,D2,INT_LIGHTS,TRT*INT_LIGHTS,

CDEV,TRT*CDEV,D1*CDEV,D2*CDEV,INT_LIGHTS*CDEV)]
 MODEL 2: IMP_CR ~
POISSON[Lambda(TRT,D1,D2,INT_LIGHTS,TRT*INT_LIGHTS,CDEV)]
 MODEL 3: IMP_CR ~ POISSON[Lambda(TRT,D1,D2,INT_LIGHTS,CDEV)]
 MODEL 4: IMP_CR ~ POISSON[Lambda(TRT,D1,D2,CDEV)]
 MODEL 5: IMP_CR ~ POISSON[Lambda(TRT,CDEV)]
 MODEL 6: IMP_CR ~ POISSON[Lambda(TRT,CDEV,TRT*CDEV)]
 MODEL 7: IMP_CR ~ POISSON[Lambda(TRT,D2,CDEV,TRT*CDEV)]
 MODEL 8: IMP_CR ~ POISSON[Lambda(TRT,D2,INT_LIGHTS,CDEV,TRT*CDEV)]
              Types: A ~ UN, B ~ CS, C~ TOEP, D ~ CSH
*/
%include "D:\glmm800.sas" / nosource;

title 'MODEL 1';
```

```
title2 'type=UN';
%glimmix(
      data=DATA2,
      stmts=%str(
                        class TRT NUM D1 D2 INT_LIGHTS;
                        model IMP_CR = TRT D1 D2 INT_LIGHTS TRT*INT_LIGHTS
CDEV TRT*CDEV
                              D1*CDEV D2*CDEV INT_LIGHTS*CDEV;
                        repeated / subject=NUM type=UN;
                    ),
                    error=poisson,
                    link=log
            );
run;
title 'MODEL 2';
title2 'type=UN';
%glimmix(
      data=DATA2,
      stmts=%str(
                        class TRT NUM D1 D2 INT_LIGHTS;
                        model IMP_CR = TRT D1 D2 INT_LIGHTS TRT*INT_LIGHTS
CDEV;

                        repeated / subject=NUM type=UN;
                    ),
                    error=poisson,
                    link=log
            );
run;
title 'MODEL 3';
title2 'type=UN';
%glimmix(
      data=DATA2,
      stmts=%str(
                        class TRT NUM D1 D2 INT_LIGHTS;
                        model IMP_CR = TRT D1 D2 INT_LIGHTS CDEV;
                        repeated / subject=NUM type=UN;
                    ),
                    error=poisson,
                    link=log
            );
run;
title 'MODEL 4';
title2 'type=UN';
%glimmix(
      data=DATA2,
      stmts=%str(
                        class TRT NUM D1 D2 ;
                        model IMP_CR = TRT D1 D2 CDEV;
                        repeated / subject=NUM type=UN;
                    ),
                    error=poisson,
                    link=log
            );
run;
title 'MODEL 5';
```

```
title2 'type=UN';
%glimmix(
      data=DATA2,
      stmts=%str(
                          class TRT NUM ;
                          model IMP_CR = TRT CDEV;
                          repeated / subject=NUM type=UN;
                     ),
                     error=poisson,
                     link=log
        );
run;
title 'MODEL 6';
title2 'type=UN';
%glimmix(
      data=DATA2,
      stmts=%str(
                          class TRT NUM ;
                          model IMP_CR = TRT CDEV TRT*CDEV;
                          repeated / subject=NUM type=UN;
                     ),
                     error=poisson,
                     link=log
        );
run;
title 'MODEL 7';
title2 'type=UN';
%glimmix(
      data=DATA2,
      stmts=%str(
                          class TRT NUM D2;
                          model IMP_CR = TRT D2 CDEV TRT*CDEV;
                          repeated / subject=NUM type=UN;
                     ),
                     error=poisson,
                     link=log
        );
run;
title 'MODEL 8A';
title2 'type=UN';
%glimmix(
      data=DATA2,
      stmts=%str(
                          class TRT NUM D2 INT_LIGHTS;
                          model IMP_CR = TRT D2 INT_LIGHTS CDEV TRT*CDEV;
                          repeated / subject=NUM type=UN r;
                     ),
                     error=poisson,
                     link=log
        );
run;
title 'MODEL 8B';
title2 'type=CS';
%glimmix(
      data=DATA2,
```

```
      stmts=%str(
                         class TRT NUM D2 INT_LIGHTS;
                         model IMP_CR = TRT D2 INT_LIGHTS CDEV TRT*CDEV;
                         repeated / subject=NUM type=CS r;
                     ),
                     error=poisson,
                     link=log
          );
run;
title 'MODEL 8C';
title2 'type=TOEP';
%glimmix(
      data=DATA2,
      stmts=%str(
                         class TRT NUM D2 INT_LIGHTS;
                         model IMP_CR = TRT D2 INT_LIGHTS CDEV TRT*CDEV;
                         repeated / subject=NUM type=TOEP r;
                     ),
                     error=poisson,
                     link=log
          );
run;
title 'MODEL 8D';
title2 'type=CSH';
%glimmix(
      data=DATA2,
      stmts=%str(
                         class TRT NUM D2 INT_LIGHTS;
                         model IMP_CR = TRT D2 INT_LIGHTS CDEV TRT*CDEV;
                         repeated / subject=NUM type=CSH r;
                     ),
                     error=poisson,
                     link=log
          );
run;
/*
                                    MODEL 1: Fit Statistics

                          -2 Res Log Likelihood           796.3
                          AIC (smaller is better)         816.3
                          AICC (smaller is better)        817.1
                          BIC (smaller is better)         839.6

                                    MODEL 2: Fit Statistics

                          -2 Res Log Likelihood           721.1
                          AIC (smaller is better)         741.1
                          AICC (smaller is better)        741.9
                          BIC (smaller is better)         764.4

                                    MODEL 3: Fit Statistics

                          -2 Res Log Likelihood           706.6
                          AIC (smaller is better)         726.6
                          AICC (smaller is better)        727.4
```

```
BIC (smaller is better)          749.9

             MODEL 4: Fit Statistics

-2 Res Log Likelihood            704.5
AIC (smaller is better)          724.5
AICC (smaller is better)         725.3
BIC (smaller is better)          747.8

             MODEL 5: Fit Statistics

-2 Res Log Likelihood            702.5
AIC (smaller is better)          722.5
AICC (smaller is better)         723.3
BIC (smaller is better)          745.8

             MODEL 6: Fit Statistics

-2 Res Log Likelihood            723.5
AIC (smaller is better)          743.5
AICC (smaller is better)         744.3
BIC (smaller is better)          766.8

             MODEL 7: Fit Statistics

-2 Res Log Likelihood            722.2
AIC (smaller is better)          742.2
AICC (smaller is better)         742.9
BIC (smaller is better)          765.5

             MODEL 8A: Fit Statistics

-2 Res Log Likelihood            724.2
AIC (smaller is better)          744.2
AICC (smaller is better)         745.0
BIC (smaller is better)          767.5

             MODEL 8B: Fit Statistics

-2 Res Log Likelihood            735.3
AIC (smaller is better)          739.3
AICC (smaller is better)         739.3
BIC (smaller is better)          744.0

             MODEL 8C: Fit Statistics

-2 Res Log Likelihood            734.6
AIC (smaller is better)          742.6
AICC (smaller is better)         742.7
BIC (smaller is better)          751.9

             MODEL 8D: Fit Statistics

-2 Res Log Likelihood            729.9
AIC (smaller is better)          739.9
```

```
                              AICC (smaller is better)        740.1
                              BIC (smaller is better)         751.6


*/

/**************** START LINEAR MIXED MODEL SEARCH *********************/
/*
 MODEL 1: SqrtIMP ~ NORMAL[MU(TRT,D1,D2,INT_LIGHTS,TRT*INT_LIGHTS,

CDEV,TRT*CDEV,D1*CDEV,D2*CDEV,INT_LIGHTS*CDEV), SIGMA]
 MODEL 2: SqrtIMP ~
NORMAL[MU(TRT,D1,D2,INT_LIGHTS,TRT*INT_LIGHTS,CDEV,TRT*CDEV), SIGMA]
 MODEL 3: SqrtIMP ~ NORMAL[MU(TRT,D1,D2,INT_LIGHTS,CDEV,TRT*CDEV), SIGMA]
 MODEL 4: SqrtIMP ~ NORMAL[MU(TRT,D2,INT_LIGHTS,CDEV,TRT*CDEV), SIGMA]
 MODEL 5: SqrtIMP ~ NORMAL[MU(TRT,D2,INT_LIGHTS,TRT*CDEV), SIGMA]
*/

title 'LMM MODEL 1';
title2 'type=UN';
proc mixed data=DATA2;
                        class TRT NUM D1 D2 INT_LIGHTS;
                        model SqrtIMP = TRT D1 D2 INT_LIGHTS
TRT*INT_LIGHTS CDEV
                               TRT*CDEV D1*CDEV D2*CDEV INT_LIGHTS*CDEV/
outp=OUTLMM1;
                        repeated / subject=NUM type=UN;
run;
title 'LMM MODEL 2';
title2 'type=UN';
proc mixed data=DATA2;
                        class TRT NUM D1 D2 INT_LIGHTS;
                        model SqrtIMP = TRT D1 D2 INT_LIGHTS
TRT*INT_LIGHTS CDEV TRT*CDEV/ outp=OUTLMM2;
                        repeated / subject=NUM type=UN;
run;
title 'LMM MODEL 3';
title2 'type=UN';
proc mixed data=DATA2;
                        class TRT NUM D1 D2 INT_LIGHTS;
                        model SqrtIMP = TRT D1 D2 INT_LIGHTS CDEV
TRT*CDEV/ outp=OUTLMM3;
                        repeated / subject=NUM type=UN;
run;

title 'LMM MODEL 4A';
title2 'type=UN';
proc mixed data=DATA2;
                        class TRT NUM D2 INT_LIGHTS;
                        model SqrtIMP = TRT D2 INT_LIGHTS CDEV TRT*CDEV/
outp=OUTLMM4;
                        repeated / subject=NUM type=UN r;
run;
title 'LMM MODEL 4B';
title2 'type=CS';
```

```
proc mixed data=DATA2;
                        class TRT NUM D2 INT_LIGHTS;
                        model SqrtIMP = TRT D2 INT_LIGHTS CDEV TRT*CDEV/
outp=OUTLMM4;
                        repeated / subject=NUM type=CS r;
run;
title 'LMM MODEL 4C';
title2 'type=CSH';
proc mixed data=DATA2;
                        class TRT NUM D2 INT_LIGHTS;
                        model SqrtIMP = TRT D2 INT_LIGHTS CDEV TRT*CDEV/
outp=OUTLMM4;
                        repeated / subject=NUM type=CSH r;
run;

title 'LMM MODEL 5';
title2 'type=UN';
proc mixed data=DATA2;
                        class TRT NUM D2 INT_LIGHTS;
                        model SqrtIMP = TRT D2 INT_LIGHTS TRT*CDEV/
outp=OUTLMM5 ;
                        repeated / subject=NUM type=UN r;
run;
title 'LMM MODEL 5';
title2 'type=CS';
proc mixed data=DATA2;
                        class TRT NUM D2 INT_LIGHTS;
                        model SqrtIMP = TRT D2 INT_LIGHTS TRT*CDEV/
outp=OUTLMM5 solution ;
                        repeated / subject=NUM type=CS r;
run;
proc univariate data=OUTLMM4 normal plots;
 var resid;
 ods listing select plots testsfornormality;
 run;
```

B.2. Generalized Linear Mixed Model Results

MODEL 8A
type=UN

The Mixed Procedure

Model Information

Data Set	WORK._DS
Dependent Variable	_z
Weight Variable	_w
Covariance Structure	Unstructured
Subject Effect	NUM
Estimation Method	REML
Residual Variance Method	None
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Between-Within

Class Level Information

Class	Levels	Values
TRT	2	0 1
NUM	76	26 28 34 43 51 52 74 75 109 112 116 121 125 150 176 177 203 227 231 233 237 265 267 268 272 298 299 339 345 349 355 361 368 389 412 439 441 459 463 467 468 469 478 486 490 497 499 572 577 582 783 791 797 809 837 841 851 855 860 861 864 865 870 873 886 897 898 914 919 942 943 969 970 975 980 981
D2	2	0 1
INT_LIGHTS	2	0 1

Dimensions

Covariance Parameters	10
Columns in X	10
Columns in Z	0
Subjects	76
Max Obs Per Subject	4
Observations Used	304
Observations Not Used	0
Total Observations	304

MODEL 8A
type=UN

The Mixed Procedure

Parameter Search

CovP1	CovP2	CovP3	CovP4	CovP5	CovP6	CovP7	CovP8	CovP9
2.1286	1.0980	1.5260	1.0166	0.7218	1.7261	0.7589	0.5727	0.7358

Parameter Search

CovP10	Res Log Like	-2 Res Log Like
1.4329	-362.1210	724.2419

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
1	1	724.24192054	0.00000000

Convergence criteria met.

Estimated R Matrix for NUM 26/Weighted by _w

Row	Col1	Col2	Col3	Col4
1	1.3296	0.6778	0.6201	0.4574
2	0.6778	0.9311	0.4351	0.3411
3	0.6201	0.4351	1.0283	0.4330
4	0.4574	0.3411	0.4330	0.8331

Covariance Parameter Estimates

Cov Parm	Subject	Estimate
UN(1,1)	NUM	2.1286
UN(2,1)	NUM	1.0980
UN(2,2)	NUM	1.5260
UN(3,1)	NUM	1.0166
UN(3,2)	NUM	0.7218
UN(3,3)	NUM	1.7261
UN(4,1)	NUM	0.7589
UN(4,2)	NUM	0.5727
UN(4,3)	NUM	0.7358
UN(4,4)	NUM	1.4329

MODEL 8A
type=UN

The Mixed Procedure

Fit Statistics

-2 Res Log Likelihood	724.2
AIC (smaller is better)	744.2
AICC (smaller is better)	745.0
BIC (smaller is better)	767.5

PARMS Model Likelihood Ratio Test

DF	Chi-Square	Pr > ChiSq
10	0.00	1.0000

Solution for Fixed Effects

Effect	TRT	D2	INT_ LIGHTS	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept				0.8447	0.1481	72	5.70	<.0001
TRT	0			-0.4700	0.1595	72	-2.95	0.0043
TRT	1			0	.	.	.	.
D2		0		0.3874	0.1482	72	2.61	0.0109
D2		1		0	.	.	.	.
INT_LIGHTS			0	-0.3477	0.2841	72	-1.22	0.2251
INT_LIGHTS			1	0	.	.	.	.
cDEV				0.000094	0.000012	72	7.93	<.0001
cDEV*TRT	0			-6.58E-6	0.000019	72	-0.35	0.7301
cDEV*TRT	1			0	.	.	.	.

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
TRT	1	72	8.69	0.0043
D2	1	72	6.83	0.0109
INT_LIGHTS	1	72	1.50	0.2251
cDEV	1	72	94.14	<.0001
cDEV*TRT	1	72	0.12	0.7301

MODEL 8A
type=UN

The Mixed Procedure

GLIMMIX Model Statistics

Description	Value
Deviance	567.9791
Scaled Deviance	567.9791
Pearson Chi-Square	495.4177
Scaled Pearson Chi-Square	495.4177
Extra-Dispersion Scale	1.0000

MODEL 8B
type=CS

The Mixed Procedure

Model Information

Data Set	WORK._DS
Dependent Variable	_z
Weight Variable	_w
Covariance Structure	Compound Symmetry
Subject Effect	NUM
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Between-Within

Class Level Information

Class	Levels	Values
TRT	2	0 1
NUM	76	26 28 34 43 51 52 74 75 109 112 116 121 125 150 176 177 203 227 231 233 237 265 267 268 272 298 299 339 345 349 355 361 368 389 412 439 441 459 463 467 468 469 478 486 490 497 499 572 577 582 783 791 797 809 837 841 851 855 860 861 864 865 870 873 886 897 898 914 919 942 943 969 970 975 980 981
D2	2	0 1
INT_LIGHTS	2	0 1

Dimensions

Covariance Parameters	2
Columns in X	10
Columns in Z	0
Subjects	76
Max Obs Per Subject	4
Observations Used	304
Observations Not Used	0
Total Observations	304

MODEL 8B
type=CS

The Mixed Procedure

Parameter Search

CovP1	CovP2	Variance	Res Log Like	-2 Res Log Like
0.7927	0.8934	0.8934	-367.6462	735.2924

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
1	1	735.29243116	0.00000000

Convergence criteria met.

Estimated R Matrix for NUM 26/Weighted by _w

Row	Col1	Col2	Col3	Col4
1	1.0656	0.4949	0.4887	0.4825
2	0.4949	1.0397	0.4827	0.4766
3	0.4887	0.4827	1.0140	0.4707
4	0.4825	0.4766	0.4707	0.9886

Covariance Parameter Estimates

Cov Parm	Subject	Estimate
CS	NUM	0.7927
Residual		0.8934

Fit Statistics

-2 Res Log Likelihood	735.3
AIC (smaller is better)	739.3
AICC (smaller is better)	739.3
BIC (smaller is better)	744.0

MODEL 8B
type=CS

The Mixed Procedure

PARMS Model Likelihood Ratio Test

DF	Chi-Square	Pr > ChiSq
1	0.00	1.0000

Solution for Fixed Effects

Effect	TRT	D2	INT_ LIGHTS	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept				0.7793	0.1554	72	5.01	<.0001
TRT	0			-0.4206	0.1642	72	-2.56	0.0125
TRT	1			0	.	.	.	.
D2		0		0.4392	0.1545	72	2.84	0.0058
D2		1		0	.	.	.	.
INT_LIGHTS			0	-0.3250	0.2900	72	-1.12	0.2661
INT_LIGHTS			1	0	.	.	.	.
cDEV				0.000100	0.000012	226	8.11	<.0001
cDEV*TRT	0			-8.54E-6	0.000020	226	-0.44	0.6622
cDEV*TRT	1			0	.	.	.	.

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
TRT	1	72	6.56	0.0125
D2	1	72	8.07	0.0058
INT_LIGHTS	1	72	1.26	0.2661
cDEV	1	226	99.29	<.0001
cDEV*TRT	1	226	0.19	0.6622

GLIMMIX Model Statistics

Description	Value
Deviance	535.4398
Scaled Deviance	599.2999
Pearson Chi-Square	488.3641
Scaled Pearson Chi-Square	546.6097
Extra-Dispersion Scale	0.8934

B.3. Linear Mixed Model Results

```
                    LMM MODEL 4A        10:02 Monday, November 3, 2003
                       type=UN

                 The Mixed Procedure

                 Model Information

Data Set                        WORK.DATA2
Dependent Variable              SqrtIMP
Covariance Structure            Unstructured
Subject Effect                  NUM
Estimation Method               REML
Residual Variance Method        None
Fixed Effects SE Method         Model-Based
Degrees of Freedom Method       Between-Within


              Class Level Information

Class          Levels    Values

TRT                 2    0 1
NUM                76    26 28 34 43 51 52 74 75 109
                         112 116 121 125 150 176 177
                         203 227 231 233 237 265 267
                         268 272 298 299 339 345 349
                         355 361 368 389 412 439 441
                         459 463 467 468 469 478 486
                         490 497 499 572 577 582 783
                         791 797 809 837 841 851 855
                         860 861 864 865 870 873 886
                         897 898 914 919 942 943 969
                         970 975 980 981
D2                  2    0 1
INT_LIGHTS          2    0 1


                     Dimensions

          Covariance Parameters            10
          Columns in X                     10
          Columns in Z                      0
          Subjects                         76
          Max Obs Per Subject               4
          Observations Used               304
          Observations Not Used             0
          Total Observations              304
```

LMM MODEL 4A 10:02 Monday, November 3, 2003
type=UN

The Mixed Procedure

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	725.64799374	
1	2	663.36737099	0.00000007
2	1	663.36736702	0.00000000

Convergence criteria met.

Estimated R Matrix for NUM 26

Row	Col1	Col2	Col3	Col4
1	0.6712	0.2917	0.2801	0.2440
2	0.2917	0.5190	0.1970	0.1475
3	0.2801	0.1970	0.5165	0.2039
4	0.2440	0.1475	0.2039	0.5148

Covariance Parameter Estimates

Cov Parm	Subject	Estimate
UN(1,1)	NUM	0.6712
UN(2,1)	NUM	0.2917
UN(2,2)	NUM	0.5190
UN(3,1)	NUM	0.2801
UN(3,2)	NUM	0.1970
UN(3,3)	NUM	0.5165
UN(4,1)	NUM	0.2440
UN(4,2)	NUM	0.1475
UN(4,3)	NUM	0.2039
UN(4,4)	NUM	0.5148

Fit Statistics

-2 Res Log Likelihood	663.4
AIC (smaller is better)	683.4
AICC (smaller is better)	684.1
BIC (smaller is better)	706.7

LMM MODEL 4A 10:02 Monday, November 3, 2003
type=UN

The Mixed Procedure

Null Model Likelihood Ratio Test

DF	Chi-Square	Pr > ChiSq
9	62.28	<.0001

Solution for Fixed Effects

Effect	TRT	D2	INT_ LIGHTS	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept				1.3584	0.1252	72	10.85	<.0001
TRT	0			-0.3083	0.1273	72	-2.42	0.0180
TRT	1			0	.	.	.	.
D2		0		0.3727	0.1340	72	2.78	0.0069
D2		1		0	.	.	.	.
INT_LIGHTS			0	-0.5276	0.2309	72	-2.29	0.0252
INT_LIGHTS			1	0	.	.	.	.
cDEV				0.000113	0.000014	72	7.90	<.0001
cDEV*TRT	0			-0.00004	0.000020	72	-2.19	0.0317
cDEV*TRT	1			0	.	.	.	.

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
TRT	1	72	5.86	0.0180
D2	1	72	7.74	0.0069
INT_LIGHTS	1	72	5.22	0.0252
cDEV	1	72	83.70	<.0001
cDEV*TRT	1	72	4.80	0.0317

The Mixed Procedure

Model Information

Data Set	WORK.DATA2
Dependent Variable	SqrtIMP
Covariance Structure	Compound Symmetry
Subject Effect	NUM
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Between-Within

Class Level Information

Class	Levels	Values
TRT	2	0 1
NUM	76	26 28 34 43 51 52 74 75 109 112 116 121 125 150 176 177 203 227 231 233 237 265 267 268 272 298 299 339 345 349 355 361 368 389 412 439 441 459 463 467 468 469 478 486 490 497 499 572 577 582 783 791 797 809 837 841 851 855 860 861 864 865 870 873 886 897 898 914 919 942 943 969 970 975 980 981
D2	2	0 1
INT_LIGHTS	2	0 1

Dimensions

Covariance Parameters	2
Columns in X	10
Columns in Z	0
Subjects	76
Max Obs Per Subject	4
Observations Used	304
Observations Not Used	0
Total Observations	304

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type=CS

The Mixed Procedure

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	725.64799374	
1	2	668.99784335	0.00000000

Convergence criteria met.

Estimated R Matrix for NUM 26

Row	Col1	Col2	Col3	Col4
1	0.5559	0.2279	0.2279	0.2279
2	0.2279	0.5559	0.2279	0.2279
3	0.2279	0.2279	0.5559	0.2279
4	0.2279	0.2279	0.2279	0.5559

Covariance Parameter Estimates

Cov Parm	Subject	Estimate
CS	NUM	0.2279
Residual		0.3281

Fit Statistics

-2 Res Log Likelihood	669.0
AIC (smaller is better)	673.0
AICC (smaller is better)	673.0
BIC (smaller is better)	677.7

Null Model Likelihood Ratio Test

DF	Chi-Square	Pr > ChiSq
1	56.65	<.0001

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type=CS

Solution for Fixed Effects

Effect	TRT	D2	INT_ LIGHTS	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept				1.3192	0.1286	72	10.26	<.0001
TRT	0			-0.2784	0.1310	72	-2.13	0.0370
TRT	1			0	.	.	.	.
D2		0		0.3958	0.1379	72	2.87	0.0054
D2		1		0	.	.	.	.
INT_LIGHTS			0	-0.5157	0.2377	72	-2.17	0.0333
INT_LIGHTS			1	0	.	.	.	.
cDEV				0.000119	0.000015	226	7.98	<.0001
cDEV*TRT	0			-0.00005	0.000021	226	-2.26	0.0248
cDEV*TRT	1			0	.	.	.	.

The Mixed Procedure
Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
TRT	1	72	4.52	0.0370
D2	1	72	8.24	0.0054
INT_LIGHTS	1	72	4.71	0.0333
cDEV	1	226	84.65	<.0001
cDEV*TRT	1	226	5.11	0.0248

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