CRASH ANALYSIS OF WORK ZONE LANE CLOSURES WITH LEFT-HAND MERGE AND DOWNSTREAM LANE SHIFT

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Abstract

The Arkansas State Highway and Transportation Department (AHTD) began the Interstate Rehabilitation Program (IRP) in the spring of 2000 that ultimately rebuilt approximately 380 miles, or 60% of Arkansas' 655-mile Interstate system. While these projects were underway, a new lane closure method, the "Iowa weave," or lane closure with a left-hand merge and lane shift, was introduced to AHTD to effectively save time ensuring that these IRP projects were completed on schedule.

Contractors on the projects used the Iowa weave at least 50% of the time for each of the projects. The settings between the Iowa weave and the conventional right-lane closure were rotated on a periodic basis depending on the work to be completed on each side of the lane. Construction officials in AHTD agreed that the use of the Iowa weave helped them to complete the rehabilitation program on time and improved traffic safety, as no major concerns were noted due to this new technique. However, the crash analysis of this weaving pattern as opposed to the conventional right-lane closure has not been assessed to determine which lane closure strategy has an advantage on the basis of actual crash experience.

This research examined the work zone crashes in both of the lane closure settings by assessing them with a set of independent variables that have been known to be the factors that influence work zone crashes. In order to properly assess the comparison between the two lane closure strategies, the following primary research objectives were pursued:

- Examination of crash experience results from the two traffic control methods, and
- Reexamination of the advantages and disadvantages of the Iowa weave method as compared to the conventional right-lane closure.

This study analyzed the crash data between January 1, 2000 and December 31, 2005 on the characteristics of lane closure strategies in Arkansas. The findings of the analyses were organized by: 1) Raw number of crashes (Pearson chi-square and One-Way ANOVA tests); 2) Crash rates (paired t-test); and Crash severity (binary logistic regression modeling).

The analysis results of this study may be used for DOTs to reference the impressive rehabilitation work that the AHTD has completed by incorporating the use of the Iowa weave. The results of the statistical analyses showed that there was approximately a 30 percent reduction in crash rate when the Iowa weave configuration was used. Nonetheless, the final results of the logistic regression model found that the safety advantages between the Iowa weave and conventional right-lane closure in changing crash severity were not statistically significant. Traffic volume was found to be the parameter that most significantly affected crash severity in the logistic regression model. Also, the effects of lighting conditions and intersecting streets on the severity of crashes were found to be insignificant.

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Finally, I take this opportunity to express my profound gratitude to my beloved parents and my girlfriend for their moral support and patience during my study at KU. Last but not least, I'm thankful to God for pulling me through all tests in the past two years.

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Chapter 1: Introduction

The Arkansas State Highway and Transportation Department (AHTD) began the Interstate Rehabilitation Program (IRP) in the spring of 2000 that ultimately rebuilt approximately 380 miles, or 60% of Arkansas' 655-mile Interstate system (*1*,*2*). A total of 54 projects were undertaken in a timeline of six years for this rehabilitation program from early 2000 to 2005. While these projects were underway, a new lane closure method, the "Iowa weave," or lane closure with a left-hand merge and lane shift, was introduced to AHTD to effectively save time ensuring that these projects were completed on schedule. Prior to this introduction, Brewer's earlier research on the Iowa weave has shown that this weave pattern is safe and effective in controlling vehicle speeds in construction work zones (*3*). This was subsequently supported by Lorscheider and Dixon (*4*), but they added that this weave pattern should be limited to rural freeways, where it is most effective in reducing speeds. In terms of time-saving, Lorscheider and Dixon recommended that contractors use it on urban freeways, where the switching from a right lane closure to a left lane closure can efficiently speed up the construction progress. In a more recent study, Zhu and Saccomanno (*5*) have found that the Iowa weave layout on a three-lane freeway segment is safer as compared to the conventional left-hand closure and right-hand closure on the basis of two safety indicators: uncomfortable deceleration and speed variances.

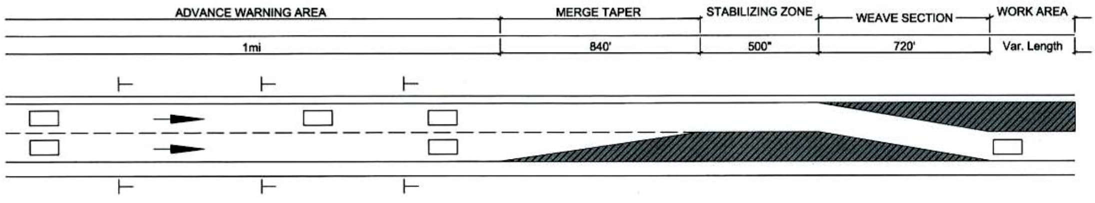


Figure 1a. LANE CLOSURE WITH LEFT-HAND MERGE AND LANE SHIFT i.e. "IOWA WEAVE"

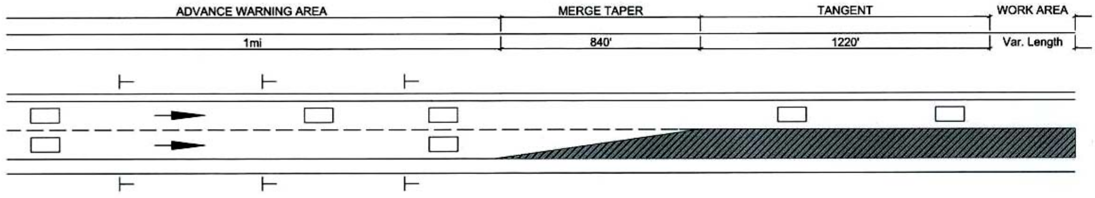


Figure 1b. LANE CLOSURE WITH LEFT-HAND MERGE i.e. "CONVENTIONAL TRAFFIC CONTROL PLANS"

Figure 1 Side-by-side comparison between the conventional traffic control plans and "Iowa weave"

Based on the estimate by the officials in AHTD, it was found that the AHTD has used the weaving pattern on 75% of their IRP projects, while the other 25% used conventional traffic control plans. Contractors on the projects always used the Iowa weave at least 50% of the time for each of the projects. The settings between the Iowa weave and the conventional right lane closure were rotated on a periodic basis depending on the work to be completed on each side of the lane. The usage of this Iowa weave setting was extensive, considering that this lane closure method had never before been used in Arkansas. After the completion of the IRP, construction officials in AHTD have positively agreed that the use of the Iowa weave has helped them to complete the rehabilitation program on time and improved traffic safety, as no major concerns were noted due to this new strategy. However, the crash analysis of this weaving pattern as opposed to the conventional right lane closure has not been assessed to determine which setting has an advantage on the basis of work zone crashes. There are many factors that may influence the crash rate on a given section of highway, including geometry, pavement condition, traffic volume, length of work zone, weather, lane closure strategy, and so forth. The focus of this research is to continue the effort of Zhu and Saccomanno (*5*) by estimating the correlation between the Iowa weave and a conventional right-hand closure through crash data and a selection of variables using the binary logistic regression.

1.1 Problem Statement

Work zone safety continues to be a high priority issue for engineering professionals and highway agencies. The national fatality rate in work zones has been constantly reported at over 1000 fatalities per year since 2000. Figure 2 shows the nationwide statistics on work zone fatalities between 1995 and 2006 (*6*). It can be observed from this illustration that the figure has dropped slightly, but the numbers remain a concern for the state transportation officials. In Arkansas alone, an average of 28 fatalities occurs in work zone crashes each year, as shown in Figure 3 (*6*). After the implementation of IRP, an increase of 10 fatalities was observed in Arkansas' annual work zone fatality rate, from an average of 22 fatalities to the current record-high average of 32 fatalities. The increase in fatal crashes occurred during the IRP period, where numerous work zones were active.

During the summers of 2000 through 2005, motorists in Arkansas encountered up to a maximum of 30 active work zones with a minimum of one lane closure per work zone (*7*). Figure 4 shows the locations of the IRP described.

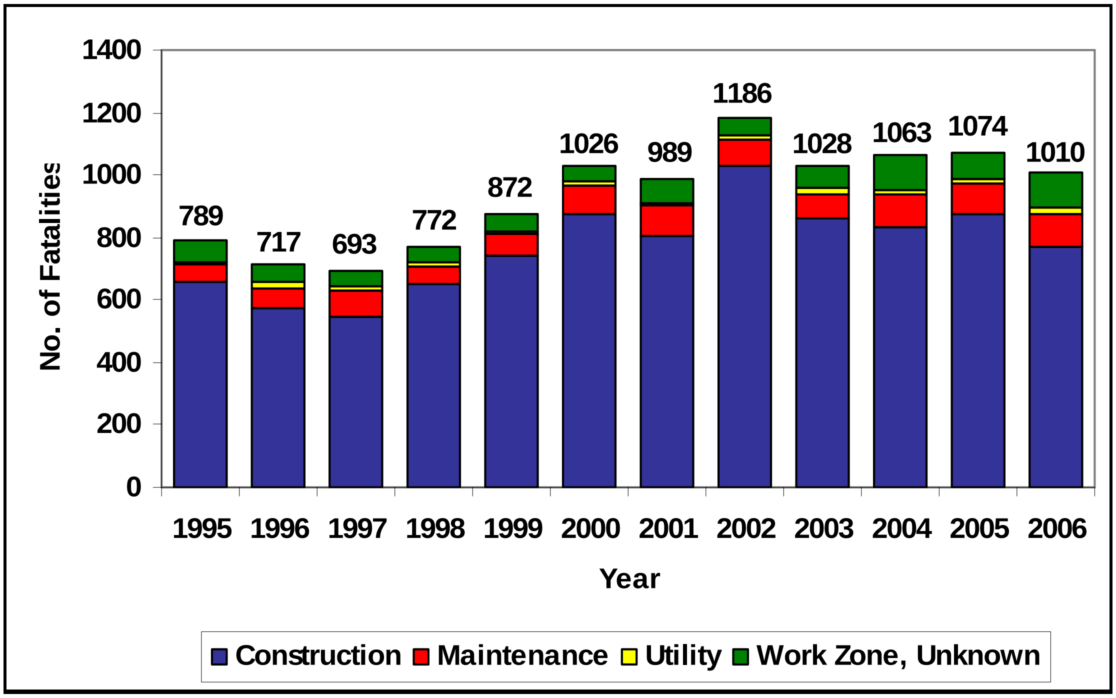


Figure 2 Twelve-year (1995-2006) nationwide work zone fatality trend (*6*)

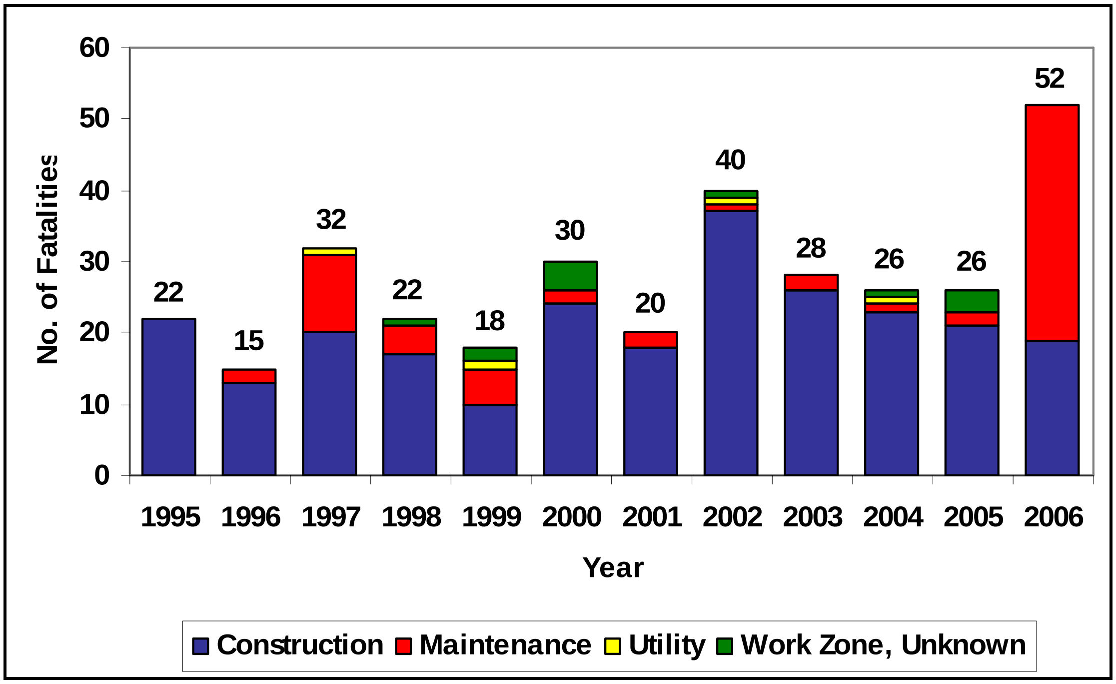


Figure 3 Work zone fatalities in Arkansas from 1995 through 2006 (*6*)

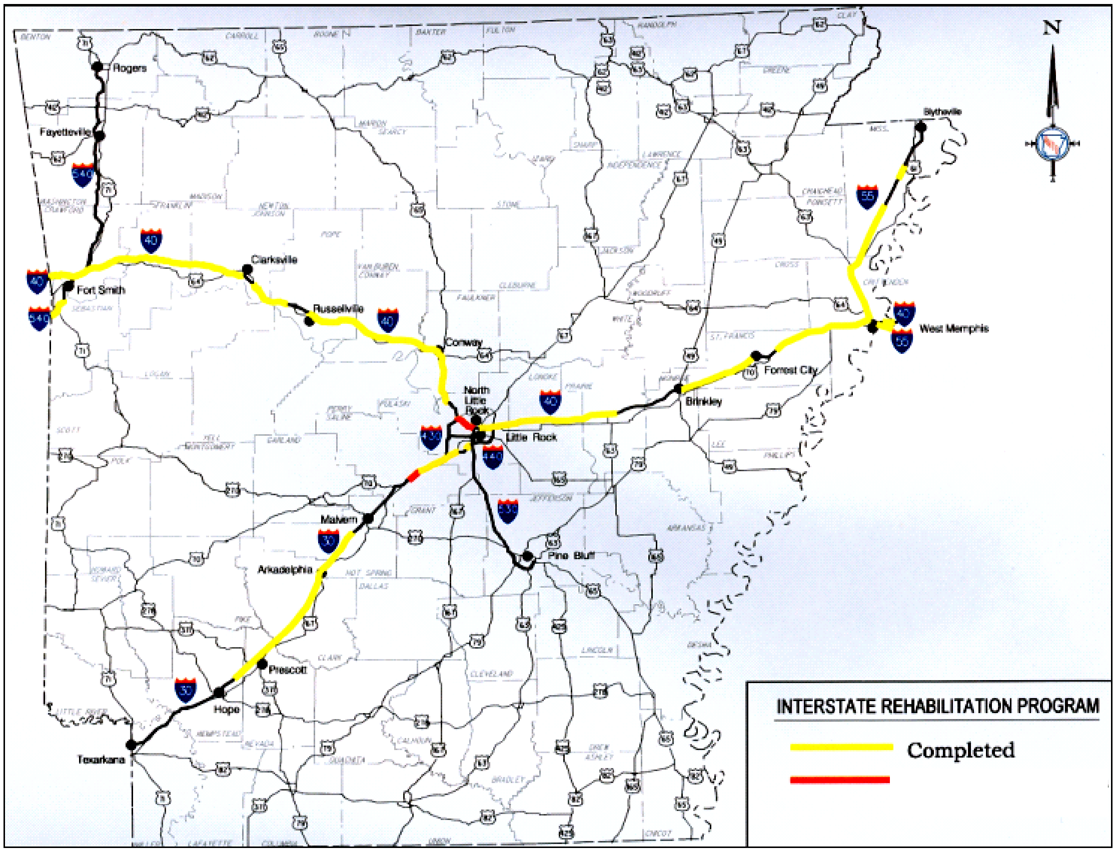


Figure 4 Interstate Rehabilitation Program from early 2000 to 2005 (*1*)

While the IRP was underway, a new lane closure method, the Iowa weave, was introduced to AHTD by the contractors. Based on the observations by the construction officials in AHTD, this new lane closure strategy effectively assisted the contractors to complete the projects on schedule. Furthermore, no major concerns were observed in work zone crashes after the introduction of this new lane closure strategy. However, the crash analysis of this new method as opposed to the conventional right-hand closure has not been examined even though a prior study has shown that the Iowa weave on the three-lane freeway segment is safer than both the conventional left-hand closure and right-hand closure based on simulation results showing uncomfortable deceleration and speed variances (*5*). This research examined the true increase of work zone crashes in both of the lane closure settings by assessing them with a set of independent variables that have been known to be the factors that influence work zone crashes. In order to accurately assess the true effect, this analysis requires a statistical tool that can account for the intrinsic variability of the sites (*8*). For instance, there may be an increase in crashes during the IRP, but the results can be biased due to the regression-to-the-mean effect (*9*,*10*), where the high crash rate is naively estimated using only the accident counts from the sites. Hauer, et al. (*10*) explained that the degree of precision (or the standard deviation) of a long period estimate where crashes occur infrequently, differ significantly from a short period estimation that comprise of many accidents, with both having the similar accident counts such as three years.

1.2 Research Objectives and Scope

In order to properly assess the comparison between the two lane closure strategies, the following research objectives were pursued:

- Examination of crash experience results from the two traffic control methods, and
- Reexamination of the advantages and disadvantages of the Iowa weave method as compared to the conventional right-lane closure.

The scope of this research was limited to the data of the whole IRP process in Arkansas, from 2000 to 2005 with the following exceptions:

- Projects that used the conventional right-lane closure only (note: these projects were designed and planned before the inclusion of the Iowa weave in the AHTD's specifications);
- Bridges or interchange projects due to the short distances involved;
- Three-lane interstate freeways in an urban setting, where two lanes were open instead of one lane;
- The interstate in question had only one IRP project (e.g. I-540 had only one project with a total distance of 6.71 miles);
- Mile markers or the log miles were not available, thus locating the work zone was not possible;
- Traffic control plans did not have information on the weave pattern (due to change orders); and
- Technology enhancement projects (e.g. the work was done on the side of the road and no lane closures were involved).

A total of 24 out of 54 IRP projects were chosen through the selection process, including 17 projects that used median crossovers. The 24 projects consisted of:

- Seventeen projects on Interstate 40 (I-40);
- Four projects on Interstate 55 (I-55); and
- Three projects on Interstate 30 (I-30).

1.3 Research Methodology

The research objectives were achieved by the following four steps:

Literature review AHTD specifications and plans, as well as other state manuals and standard traffic control plans were reviewed to determine the current policies regarding the state-of-the-art background of the Iowa weave. A comprehensive review of transportation engineering journals, articles and papers was conducted to determine previous analyses into operational and safety impacts of the Iowa weave as opposed to the conventional work zone lane closures.

The review synthesized the findings from the previous literature on work zone lane closures-related subjects, such as characteristics and effectiveness of work zone lane closures, statistical analyses of work zone crashes, and work zone analyses. This task was essential to enable the researcher to better understand the current work zone lane closure research status and to carry out an innovative and feasible study.

Data collection The fatal, injury and non-injury work zone crash data from 1999 to 2005 were collected from the AHTD. The data were then reduced and recompiled into data files that were compatible for computer-aided statistical analysis without losing important information.

Data analyses In this section, the reduced data were statistically analyzed using the SPSS statistics software package, to examine the quantified effectiveness of the Iowa weave and the right lane closure. As a precautionary measure, the logistic regression in the software package of XLSTAT was utilized to verify the results obtained from SPSS.

Conclusions and recommendations Based on the results of the statistical analyses, the conclusions and recommendations were drawn accordingly. The conclusions included important work zone crash characteristics, lane closure effectiveness, and work zone lane closure risk factors. In addition, work zone lane closure improvements and future research were also recommended in this section.

1.4 Thesis Organization

This thesis is organized into six sections. The chapters are summarized as follows:

Chapter 1: Introduction. This chapter provides the background to the thesis. The section also lists the problem statement, research objectives, and scope.

Chapter 2: Literature Review. This chapter presents the findings from a comprehensive literature review. The literature reviewed includes federal and state manuals, characteristics and effectiveness of work zone lane closures, statistical analyses of work zone crashes, and work zone analyses techniques.

Chapter 3: Data Collection and Reduction. This chapter details the methodology adopted for this research work. This includes the detailed data collection procedure and the final collected data.

Chapter 4: Work Zone Crash Analysis. This chapter presents the results of the data analyses on the characteristics of lane closure strategies. The findings of the analyses were organized by raw number of crashes, crash rates and crash severity. The section also presents the quantified effectiveness of the Iowa weave and the right-lane closure using the binary logistic regression method.

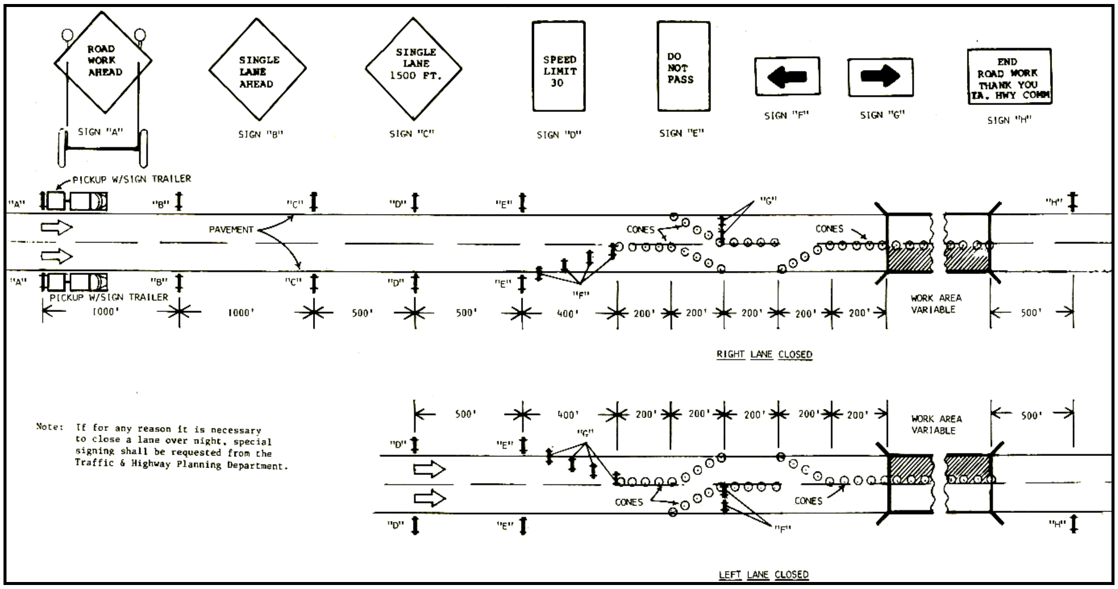
Chapter 5: Conclusions and Recommendations. Conclusions and recommendations of this research are presented in this chapter.

Chapter 2: Literature Review

2.1 History and Characteristics of Iowa Weave

2.1.1 Background

The term “Iowa Weave” is evidence that this lane closure method was initially introduced in the state of Iowa. The actual date of this introduction is not known; however, it was estimated to be prior to 1969 based on the literature (*11*). When it was first introduced, there were two Iowa weave lane closures setups: left-hand merge with lane shift, and right-hand merge with lane shift. Figure 5 shows the Iowa weave lane closures described. This pattern was initially designed to control speeds but the use was subsequently discontinued by Iowa after the introduction of median crossovers and two-lane, two-way operation (TLTWO) in work zone lane closures.



Note: If for any reason it is necessary to close a lane over night, special signing shall be requested from the Traffic & Highway Planning Department.

Figure 5 Iowa weave (left -hand and right-lane merge) (*11*)

In an earlier study, Brewer (*3*) conducted research to examine both the left-hand merge and right-hand merge Iowa weave setting on arterial roads in Des

Moines, Iowa. The unique designs of this weave pattern were often found to be an unaccustomed experience for drivers, was believed to be an effective method to control traffic speeds on freeways. The modifications of this weave pattern include the spacing in the advance warning area, merging taper and the weave section shown in Figure 5. In this research, two different methods were chosen to collect the data: camera observation and enoscopes (flash boxes). For the camera observation, a 16mm Beaulieu R-16 camera was used to record the data on weaving and merging at the advance warning area. In addition, the license plates of all vehicles sampled were recorded to classify these vehicles into different categories: Iowa same county, Iowa-other-than-local, and out-of-state. Meanwhile, the enoscopes were placed in the work areas behind the barricades to collect vehicle speeds. The placement of the enoscopes behind the barricades was to ensure inconspicuity as the presence of this device might change the driving behavior of motorists. Brewer explained that this measure was to prevent bias in the data.

The results of this research found that this weaving pattern was highly effective in construction sites, with more than 50% of all vehicles sampled traveling below the posted temporary speed limit of 30 miles per hour (mph), whereas in construction sites where the forced weaving was not used, the posted speed limit compliance of all vehicles sampled was found to be less than 20% (*3*). The chosen speed limit of 30 mph was considered by Brewer as the desirable speed where vehicles should be constricted. In this research, Brewer concluded that no excessive driver confusion was found in the use of this weave pattern, even though three vehicles were found performing unusual maneuvers in the advance warning area.

2.1.2 Federal and State Review

Since the introduction of the Iowa weave, many state Departments of Transportation (DOTs) have experimented with this new weave pattern. Iowa, North Carolina, and Tennessee along with Arkansas have each used the Iowa weave lane closure setting on their freeways. Based on the instructional bulletin by the Tennessee DOT on the use of the Iowa weave (also known as lane closures with left-hand merge), Tennessee requires all of their interstate construction and maintenance projects to review and include the use of the merge left where lane closure is applicable (*12*). However, the following criteria must be fulfilled before determining the use:

- “Projects on rural interstates should include Merge Left.”
- “Projects on urban interstates will be reviewed for Merge Left considering factors such as number of lanes, interchange spacing, and proximity to major splits.”
- “Other controlled access facilities will be considered on a case-by-case basis.”

In North Carolina (*4*), this weave pattern was first borrowed from the Iowa DOT after a tractor-trailer breached the approach taper and buffer zone in a work zone on I-77, and struck the construction personnel. This incident alerted the officials in the North Carolina DOT and the Iowa weave was subsequently adopted to control traffic in high speed, medium volume work zones. The main purpose of this adoption by the North Carolina DOT was to ensure the safety of construction personnel when any errant vehicles penetrated the closed lane, as the Iowa weave would provide an additional buffer space between traffic and where construction workers are actively working.

2.1.3 Characteristics of Iowa Weave

In the 1990s, Lorscheider and Dixon (*4*) examined the effect of the Iowa weave by evaluating the speeds at the advance warning, end of taper, weave and lane closure areas on both rural and urban freeways. In this study, Vehicle Magnetic Imaging traffic counters or analyzers were utilized to monitor the vehicle speeds in the project area. The only concern observed in this device was the limitation of detecting vehicles traveling above the upper threshold of 80 mph. The results of this research showed that this weave pattern was effective in reducing the speeds of motorists in work zones despite the authors' anecdotal report of complaints of driver confusion in urban settings. Consequently, the authors recommended that the use of this weave pattern should be limited to rural freeways. In addition, it was found that the speed reduction resulting from the weave section dissipates within ¾ of a mile after the advance buffer area. Nonetheless, Lorscheider and Dixon stated that this unique design is a great tool to protect workers as it directs motorists to drive through the merging taper and stabilizing zone on the left lane before channelizing them over to the right lane to avoid the actual work area ahead of them.

In the paper, Lorscheider and Dixon concluded that the Iowa weave can be a great time saving method for contractors in construction work zones even though "numerous" drivers were confused by the direction of the advance signs that led them to the lane that was closed. Table 1 shows the results of the drivers behavior described.

Table 1 Drivers Modifying Behavior Due to Changeable Message Sign (*4*)

Type of driver behavior modified	Rural below capacity	Urban below capacity	Urban approaching capacity
Speed increase	Unknown	9%	6%
Lane switching	12%	2%	9%

Depending on the size of the work zones, a lane closure involving an advance warning area on an urban freeway can take up to two hours to set up and remove. Furthermore, contractors are often permitted to have a ten-hour window at night to set up the lane closures. With such regulation, contractors can spend a substantial amount of time installing and removing the lane closures, but by using the Iowa weave, contractors can remove the weave section, which normally takes less than twenty minutes, and leave the entire length of the lane closures in an extended straight buffer area. The Iowa weave also helps eliminate the use of right-lane closures, which requires the relocation of advance warning signs and reduces driver confusion to motorists that drive by the area on a routine basis. In order to ensure the safety of construction personnel, slow moving convoys, or “rolling roadblocks” can be used in the operation to switch from right lane closures to left lane closures.

Lorscheider and Dixon also indicated that the Iowa weave can be used on three-lane, one-way work zones, by closing two lanes and allowing vehicles to weave through the center lane to the far side of the work zones. When the construction workers signal the need for the lane closure to be swapped to the opposite side, the weave section is again removed, leaving the two lane closures with an extended buffer (transformed to conventional lane closure). There are two additional benefits observed in using this method over the two-lane, one-way weave pattern. First, the three-lane, one-way weave pattern allows an additional buffer area between the workers and the open travel lane. Second, this technique also provides additional time for the contractors to remove the lane closure in the center lane. With proper attention, contractors can place the buffer zone and a weave at the midpoint of the work zone to facilitate two different construction activities on two separate lanes concurrently. For example, contractors can pave the upstream left lane (or inside lane) while cold milling the downstream right lane (or outside lane). However, Lorscheider and Dixon recommended that the three-lane work zone setup be examined with extra care as this type of closure increases driver confusion. Figure 6 shows the Iowa weave on three-lane freeway described.

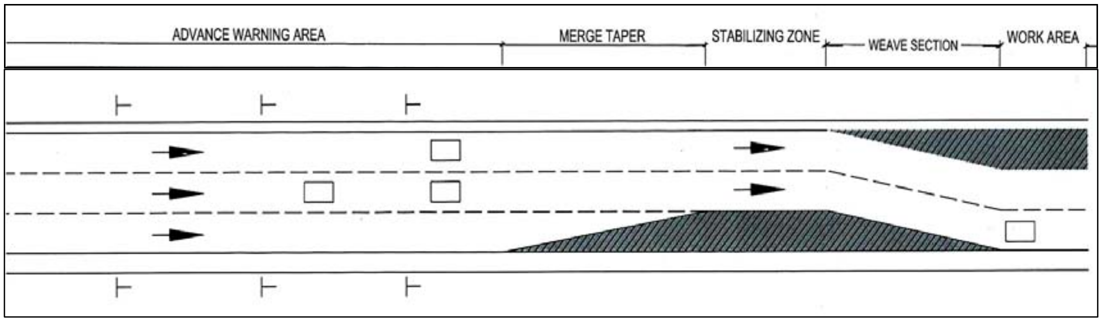


Figure 6 Iowa weave on three-lane freeway

In the most recent literature on the Iowa weave, Zhu and Saccomanno (*5*) conducted research to compare both the left-hand closure and right-hand closure, while proposing and comparing a more channelized lane closure layout (or the Iowa weave) on the three-lane freeway. The focus of this research, however, was to examine the safety implications of these lane closure methods by measuring two traffic-flow characteristics using the microlevel simulation (INTEGRATION): uncomfortable deceleration and speed variances. In other words, the higher values found in uncomfortable deceleration and speed variances denote that the lane closure method may be prone to higher risk for work zone collisions. Based on the simulation results of this research, it was found that the right hand closure appears to be safer than the left hand closure, whereas the proposed layout on a three-lane freeway segment was found to be safer than both the left-hand closure and right-hand lane closure. Zhu and Saccomanno also explained that the proposed layout helps to avoid high-risk lane changing that could occur on the higher speed left lane than the lower-speed right lane. Also similar to Lorscheider and Dixon's explanations, the high risks in merging maneuvers can be relocated to the advance warning area, which is farther away from the workers. In terms of positive guidance (*13*), Zhu and Saccomanno found that this layout helps reduce the uncertainty associated with lane closure merging by reducing the choices that drivers will have to make in lane closures and increase driver awareness. However, this proposed layout, just like any other method, is not perfect: one possible disadvantage observed in this method is the increase in traffic turbulence that could occur on the lane shifting area, as vehicles would be required to move to open lanes before they reach the work area.

The following are the key findings of Zhu and Saccomanno's research:

- A lower number of uncomfortable decelerations were observed in the advance warning area, buffer and work areas of the proposed layout (the Iowa weave).
- The results in the termination area of the proposed layout were not statistically significant.
- The current layout, the conventional left hand closure was found to be safer than the proposed layout in the transition area due to the capacity reduction in the downstream lane shifting area that caused the queue to back to the upstream transition area.
- The results were consistent in both the flow rates of 2,800 vph and 3,600 vph.
- Overall, a higher number of uncomfortable decelerations was obtained for the current left-hand closure.

- The safety advantages of the proposed layout over the current right-hand closure was not as significant as for the left-hand closure.
- Significant differences were observed in speed variances between the proposed layout and the current left-hand closure, even though the results of the buffer area in the classification of 2,800 vph were found to be counterintuitive.
- The proposed layout and the right-hand closure appeared to result in similar speed variances.

2.1.4 Additional Iowa Weave Research

The Texas Transportation Institute (TTI) has also conducted research to evaluate the effectiveness of various lane closure strategies for work zones on four-lane divided highways (*14*). The research was focused on evaluating speed reduction in each work zone speed control technique instead of lane closure strategies. The Iowa weave lane closure strategy was stated as one of the work zone speed control methods in this research. However, this weave pattern was not selected as one of the methods for evaluation due to its lack of availability. Richards et al. (*14*) stated in the research that the overall and relative effectiveness of the work zone speed control methods including the Iowa weave were not known even though these techniques have been used by many state agencies.

2.2 Statistical Methods, Analysis and Evaluation

Statistical methods that are used to estimate safety effects of treatment have improved over the years through the efforts of transportation researchers by uncovering pros and cons of each procedure. Prior to this, many conventional methods had been used to estimate the safety effects of a treatment. These methods, however, are often found to be ill-suited in practice (*15*). First, the randomness of entities like road sections, intersections, drivers, and vehicles has always made applying the treatment or measure difficult. Furthermore, the matching between the treated and untreated entities often caused the statistical procedure to become a challenging task for researchers to accomplish. Lastly, the reality that the number of treated entities is influenced by factors such as budget, politics, and availability and not by the requirements of statistical significance is another concern. The issue of mismatching between fulfilling the requirements of conventional methods and what realities can offer often are the challenges that researchers have to face when estimating the safety effects of a treatment. The lack of precision is one evident finding that can be observed from the literature, however, the magnitude of the safety effect is the bigger concern, as researchers often resort to common sense to estimate if a treatment will improve or degrade it.

2.2.2 Crash Analysis Background

Over the years, two major statistical procedures have been frequently used for crash data analyses: Bayesian and non-Bayesian approaches (also known as the frequentist approach). The Bayesian approach has been a popular choice used among researchers because it takes care of the regression-to-the-mean effect (*16*). The Bayesian approach can be broken down into two different classifications: pure Bayesian and empirical Bayes method (*16*). The non-Bayesian approach can be classified into three different categories: before-and-after study, before-and-after study with yoked comparison, and before-and-after study with comparison and check for comparability (*10*). Figure 7 shows the statistical procedures described. The empirical Bayes approach has been the most desirable statistical method used by traffic safety engineers due to the effective arguments by proponents regarding its advantages (*17*). However, Carriquiry and Pawlovich (8) argued that the empirical Bayes method suffers a few drawbacks. The most significant one is the need to spend time, resources, and effort to obtain the Safety Performance Functions (SPFs), which are required for the empirical Bayes method. Carriquiry and Pawlovich also explained that the pure Bayesian approach can improve the prediction of the number of crashes while avoiding the need to obtain the SPFs and other quantities like Accident Modification Factors (AMFs).

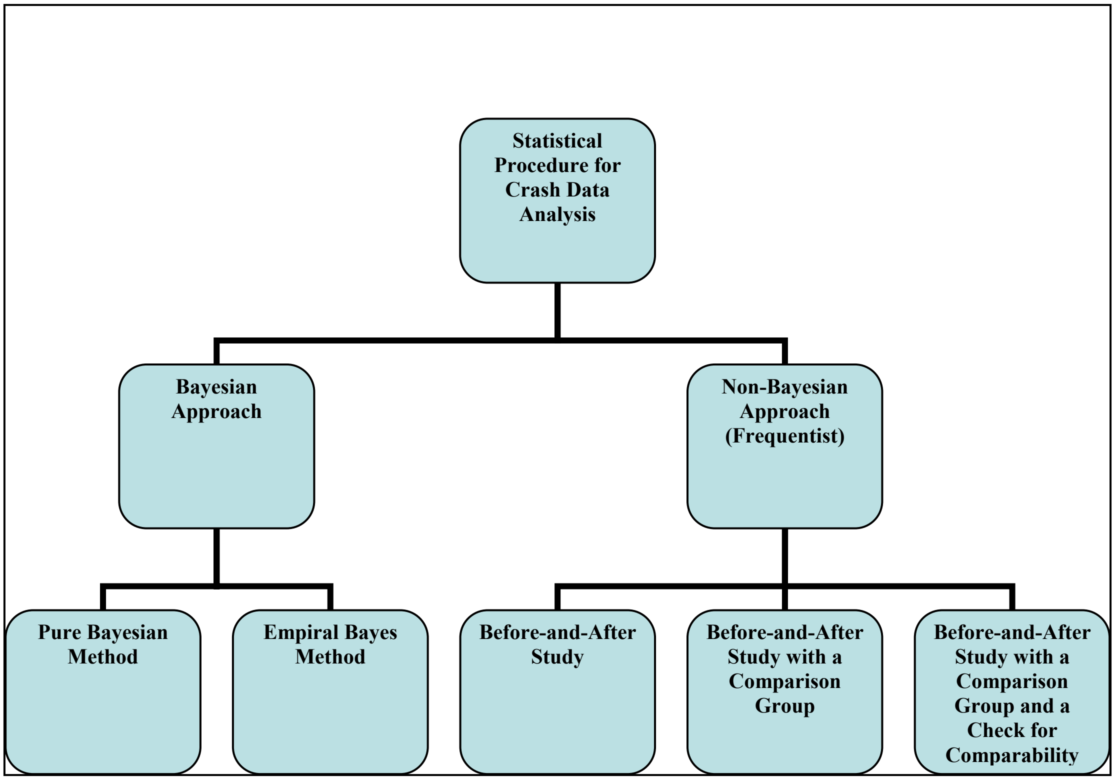


Figure 7 Statistical procedure for crash data analysis

2.2.3 Bayesian Approach: Pure Bayesian and Empirical Bayes Method

The research conducted by Carriquiry and Pawlovich found that both the empirical Bayes and full Bayesian methods recognize that similar intersections will have a similar number of expected accidents but not identical. The findings of this research also showed that the estimate of site's safety might be unreliable if only a few years of information is obtained for the study location. Thus, Carriquiry and Pawlovich emphasized that it is critical to 'borrow' information from similar locations to balance the scarce data. The results of this research also found that the empirical Bayes approach used the estimated parameters from the results of SPFs fitting as if they were true values and this implied that population level estimates do not contribute to the uncertainty in estimating the safety of a particular research site. Carriquiry and Pawlovich added that it is often found that empirical Bayes analysts find impractically low standard errors in their estimates. In the research, Carriquiry and Pawlovich concluded that the pure Bayesian method is a less costly approach as compared to the empirical Bayes method. Additionally, it was argued that the pure Bayesian method is easier to implement and has the potential to provide estimates that are more reliable. However, Carriquiry and Pawlovich stated that practitioners are advised to select prior distributions of the parameters model in accordance to the information available prior to studying the data. The conclusions also found that selecting the prior distributions for the pure Bayesian method is similar to assessing the SPFs for the empirical Bayes method. Carriquiry and Pawlovich explained that the pure Bayesian method is typically tougher on deficient specifications of the prior distributions than the empirical Bayes estimates are to poor SPFs estimates. In essence, the pure Bayesian methods are often insensitive to different specifications of prior distribution in estimating the number of crashes as long as a significant amount of site information is available over a few years. However, a proper pure Bayesian statistical analysis should include a sensitivity assessment of different prior specifications.

Many studies have shown that the empirical Bayes method is a desirable statistical method for safety estimation as this technique addresses two problems: precision of assessments and regression-to-the-mean bias (*10*,*16*). In an effort to put the complex theory of empirical bayes into practice, Hauer, et al. have conducted tutorial research to evaluate the statistical procedure. In the research, Hauer, et al. showed that safety entities such as road sections, intersections, drivers, and vehicles are usually estimated from the history of its crash counts and the method combines crash counts with the history of same entities for the empirical Bayes procedure. The researchers added that by following the above steps, the precision of estimates is improved when crash records are sparse and the regression-to-the-mean concern is taken care of. The study also found that the precision of assessments can be further increased by adding the estimates of SPFs of the same entities and an estimate of applicable overdispersion variables.

For the empirical Bayes method, the multivariate empirical Bayes method (also known as the empirical Bayes with covariates) is a preferred method over the conventional approaches among practitioners as it estimates the reference group crash experience (*10*, *16*). This statistical procedure estimates the weights and the number of crashes expected at study sites similar to the treated ones by calibrating and using a multivariate model or safety performance function (SPF) that relates the crash experience, and traffic and physical characteristics of sites. However, this statistical method has two drawbacks: suitable reference data for calibration purposes are hard to locate and the calibration of multivariate models is a complex process. In order to overcome this, analysts can reference models and populations of similar interest developed by others.

2.2.4 Non-Bayesian Approach: Before-and-After Study

For the non-Bayesian approach, many studies have been conducted in the past to evaluate the methodology and perhaps the most popular one is the book by Hauer (*10*). In the book, various crash related problems and the latest techniques regarding the before and after observations were discussed in detail. The key concept was the recognition to separate the changes from a treatment and other factors such as fluctuation of crash counts, traffic volume changes, and patterns in crash occurrence in order to estimate the true effect. Hauer also explained that before-and-after studies provide the guidance of accounting the uncertainty in the results of crash occurrence by considering the variation in traffic volumes.

The non-Bayesian approach can be broken down into three categories: before-and-after study, before-and-after study with yoked comparison and before-and-after study with comparison and check for comparability (*10*). The simple before-and-after study is the most common statistical procedure used by practitioners. However, this direct method was simply not a good estimate to evaluate the before-and-after effect as it does not take into account factors other than the treatment, when changes from a treatment should be separated from other factors such as traffic volume changes and patterns of crash occurrence in order to accurately assess the true effect of treatment (*15*). As compared to the simple before-and-after study, the before-and-after study with yoked comparison is a better option to estimate the effect of a treatment. This method uses four measures per treatment site, before and after at a treatment site and before and after at a comparison site to ensure extraneous factors other than the treatment are carefully categorized. Previous in-depth studies have found that the before-and-after study with comparisons and check for comparability is a desirable statistical procedure as it reviews the compatibility of the comparison while checking the effect of the treatment (*10*). This comparability check reviews the treatment effect by using the crash patterns in the comparison group to match with the before and after period to ensure that it reduplicates to provide the 'mirror' effect. For instance, the percent decrease in crashes per year in the treatment group during the before and after period should be similar in order to obtain the 'mirror' effect.

2.2.5 Regression-to-Mean Effect

The regression-to-the-mean bias has always been a concern for practitioners in estimating safety improvements. The observational before-and-after evaluations are typically the statistical method to be affected by it, and some studies have argued that this methodology is always biased. In order to address this issue, Sharma and Datta (*18*) conducted a study to compare the regression-to-the-mean effect of both the observational before-and-after studies and empirical Bayes method (suggested by instrumental proponents). The study examined the regression-to-the-mean effect by using the before-and-after studies, before-and-after studies with control sites and two different variants of the empirical Bayes method, and found that the expected accident frequencies by all four methods do not differ significantly when 3 to 5 years of traffic accident data are used. The research concluded that the before-and-after studies and empirical Bayes method produce similar results; however, the regression-to-the-mean effect becomes insignificant when 3 or more years of accident data are used for estimation in high accident sites.

2.2.6 Logistic Regression

Logistic regression has been developed and used by practitioners to estimate safety improvements for some time. The significance of this method in the analysis of traffic safety has been recognized by many researchers over the past several years (*19*,*20*). The binary logistic regression analysis is a statistical method that identifies the correlation between a set of independent variables and a dichotomous response variable or outcome (*21*). In essence, this methodology uses a model to predict the likelihood of an outcome by identifying the causal factors (*20*). Similarly, like the Bayesian and non-Bayesian statistical approach, logistic regression also suffers a few drawbacks (*22*). This large-sample method can cause considerable bias if particular types of matched sets occur irregularly in the procedure or the model is comprised of an excessive amount of parameters. However, this sparse data bias can be avoided by carefully inspecting the data and scrutinizing the sensitivity of estimates to group boundaries, parameters in the model, and changes in those parameters. Additionally, the bias problem can also be resolved by resorting to statistical procedures, which are less sensitive to sparse data, such as the pure Bayesian and empirical-Bayes method.

Kim, Kim and Yamashita (*23*) have conducted research using logistic regression to investigate the likelihood of alcohol impairment among crash-involved motorcycle riders in police reported motorcycle crashes. In this research, the

Statistical Analysis Software (SAS) was utilized to estimate the parameters of the logistic regression model. The model fit was assessed by testing the null hypothesis that the covariates have no effect on the response variable by using a likelihood ratio. The results of this research showed that impairment was more likely to happen among middle-aged riders and unlicensed riders, who did not use a helmet, and that impaired-related crashes are more prone to happen at night, on weekends and in rural areas.

2.2.7 Other Statistical Procedures

In crash analysis, many statistical procedures have been experimented and used by practitioners to estimate safety improvements. Whether it was to compare a group, quantify the association between two variables, or predict the value from variables, the crash data can be statistically analyzed for safety estimation using a suitable statistics method. However, the only limitation observed is carefully inspecting the type of data before identifying the appropriate statistics test. Table 2 shows the applicable statistics tests described.

Conventionally, researchers have used different statistical procedures to estimate and predict the impact of the safety improvements: binary logit models, linear and non-linear regression, and the Pearson chi-square test. However, just like any other statistical procedures, there are pros and cons in each of these techniques.

Table 2 Other Statistical Procedures for Data Analysis (*24*)

	Type of Data			
Goal	**Measurement (from Gaussian Population)**	**Rank, Score, or Measurement (from Non-Gaussian Population)**	**Binomial (Two Possible Outcomes)**	**Survival Time**
Describe one group	Mean, SD	Median, interquartile range	Proportion	Kaplan Meier survival curve
Compare one group to a hypothetical value	One-sample *t* test	Wilcoxon test	Chi-square or Binomial test	
Compare two unpaired groups	Unpaired *t* test	Mann-Whitney test	Fisher's test (chi-square for large samples)	Log-rank test or Mantel-Haenszel
Compare two paired groups	Paired *t* test	Wilcoxon test	McNemar's test	Conditional proportional hazards regression
Compare three or more unmatched groups	One-way ANOVA	Kruskal-Wallis test	Chi-square test	Cox proportional hazard regression
Compare three or more matched groups	Repeated-measures ANOVA	Friedman test	Cochrane Q	Conditional proportional hazards regression
Quantify association between two variables	Pearson correlation	Spearman correlation	Contingency coefficients	
Predict value from another measured variable	Simple linear regression or Nonlinear regression	Nonparametric regression	Simple logistic regression	Cox proportional hazard regression
Predict value from several measured or binomial variables	Multiple linear regression or Multiple nonlinear regression		Multiple logistic regression	Cox proportional hazard regression

Ouyang, et al. (*25*) have developed a simultaneous binary logit model to examine the interrelationships among the injury severity outcomes in multi vehicle collisions. The findings of this research showed that the model provided significant efficiency gain in determining the impacts of various factors such as different vehicle types, collision vehicle conditions, driver and occupant factors, collision locations, and speed limits, and weather-related factors. The authors concluded that their simultaneous multinomial logit model was more efficient than traditional ones. However, the only downside observed in this procedure is that this statistical method can only model one severity at a time, which is time consuming.

Garber and Ehrhart (*26*) were one of the few that have conducted safety improvement research using non-linear regression models. In this study, factors such as traffic characteristics, environmental and road conditions, and road geometry on two-lane highways were examined by using the Akaike Information Criterion (AIC) instead of R^2 to determine the accuracy of regression. The key findings of this study showed that the four non-linear regression models could estimate real crash experience in terms of standard deviation of speed, flow per lane, lane width, and shoulder width. However, it was found that these crash prediction models were too sophisticated to be applicable in practice. In addition, the models could not be applied directly to other models as the database was limited to Virginia two-lane roads.

The problem of large parameters has constantly been a concern among traffic safety practitioners. The main concern in this issue is the accuracy of assessments, which may be affected by this large number of factors. In order to address the issue, Chen and Jovanis (*27*) have developed a variable-selection procedure using the Pearson chi-square test to examine the most significant factors that affect traffic crashes. The researchers concluded in this study that the new procedure was superior in three major tasks:

- Truncating the number of groups by collapsing them while maintaining the homogeneity in each group,
- Preventing sparse data bias, and
- Separating the parameters that may or may not be the causal factors to the response variable.

Similar to the simple logistic regression method, the Pearson chi-square test requires substantial amounts of efforts in carefully inspecting the data before running the test.

2.3 Work Zone Lane Closure and Analysis

2.3.1 Work Zone Lane Closure

Lewis (*28*) defined a lane closure as an operation to close a traffic lane in such a manner that traffic is forced to move out of the closed lane and merge into the open lane. Generally, a long-term lane closure is used in work zones for construction work such as resurfacing and restoration to be undertaken in the closed lane. A typical lane closure consists of an advance warning area, a transition area (also known as merging taper), an activity area and a termination area (also known as downstream taper). The activity area can be broken down into two areas: buffer space and workspace. Figure 8 shows the lane closure described.

The advance warning area serves as an important section in the work zone, where the motorists get information regarding the upcoming work ahead of them. The placement of advance warning signs in this area may vary for different types of roadways; however, for expressways or freeways the signs are generally spaced in longer sections to encourage uninterrupted flow. Table 3 shows the suggested advance warning spacing for a typical work zone lane closure. Letters A, B and C in table 3 denote the suggested spacing between signs in a particular lane closure condition.

Table 3 Suggested Advance Warning Spacing (*29*)

Road Type	**Distance Between Signs, meter (feet)**		
	A	**B**	**C**
Urban (low speed)	30 (100)	30 (100)	30 (100)
Urban (high speed)	100 (350)	100 (350)	100 (350)
Rural	150 (500)	150 (500)	150 (500)
Expressway/Freeway	300 (1000)	450 (1500)	850 (2460)

The tapers for lane closure are channelizing devices to move traffic in and out of the regular path. In order for it to function properly, it is crucial to use appropriate lengths of taper for a lane closure, as longer tapers are not necessarily better than shorter tapers and vice versa.

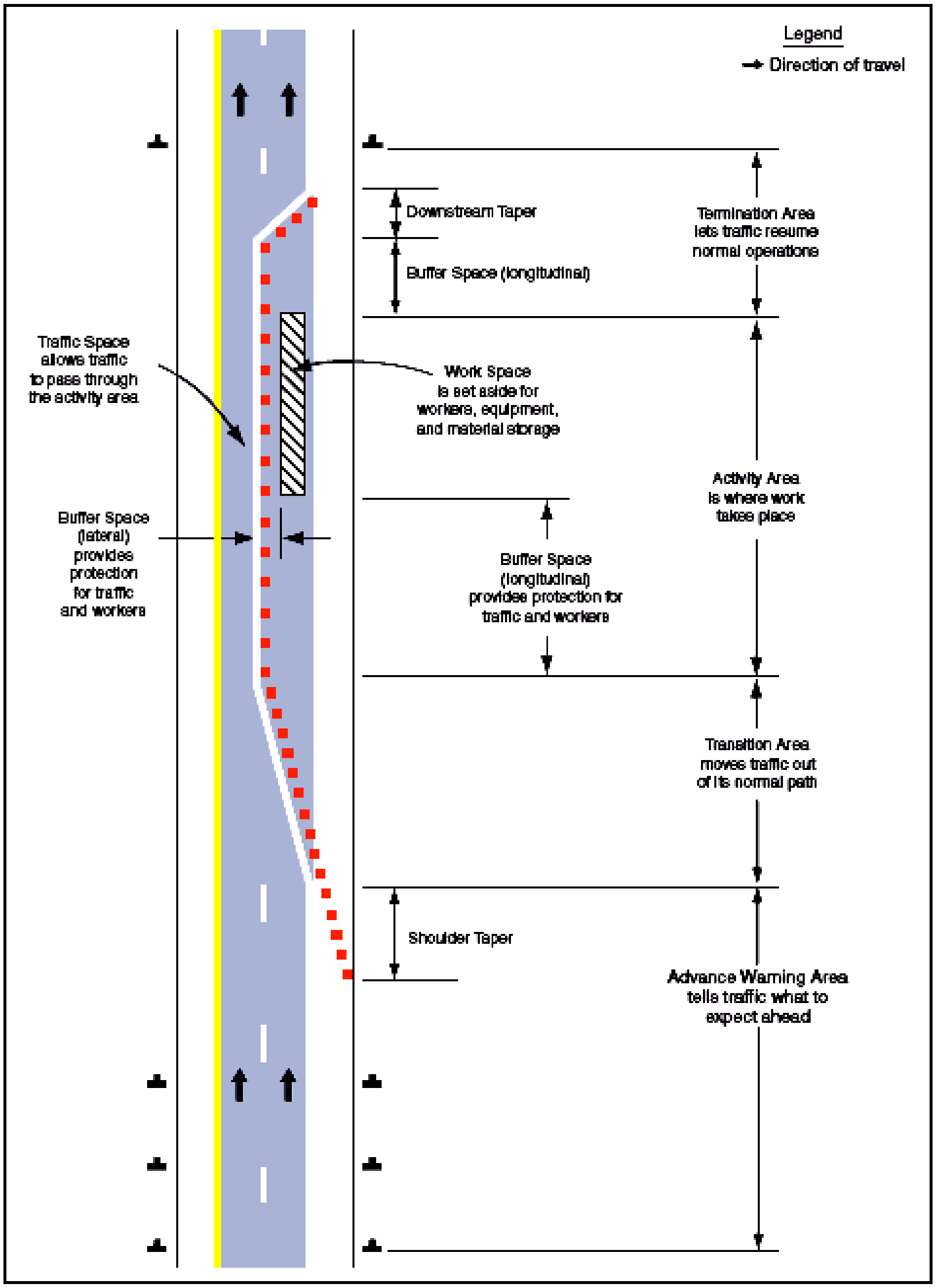


Figure 8 Layout of a typical lane closure (*29*)

The Manual on Uniform Traffic Control Devices (MUTCD) explains that extended tapers might encourage unnecessary delays in lane changing and sluggish operation. Pigman, et al. (*30*) echoed the MUTCD in their findings that over 95% of drivers on the southern Kentucky freeway changed lanes before reaching the transition area (or merging taper), while the remaining 5% of drivers used the taper in the transition area to make the required lane changes. Table 4 shows the taper length criteria for temporary traffic control zones. The letter L used in Table 4 denotes the suggested taper length for different types of taper. The length of taper can be calculated by using an equation stated in the Table 5, based on the speed limit of the work zone.

Table 4 Taper Length Criteria for Temporary Traffic Control Zones (*29*)

Type of Taper	Taper Length (L)
Merging Taper	at least L
Shifting Taper	at least 0.5L
Shoulder Taper	at least 0.33L
One-Lane, Two-Way Traffic Taper	30 m (100 ft) maximum
Downstream Taper	30 m (100 ft) per lane

Table 5 Formulas for Determining the Taper Lengths (*29*)

Speed Limit (S)	Taper Length (L) Feet
40 mph or less	$L = WS^2/60$
45 mph or more	$L = WS$

L = taper length in meters (feet)
W = width of in meters (feet)
S = posted speed limit or the anticipated operating speed in km/h (mph)

The MUTCD provides specific guidelines for the use of work zone lane closure. For single lane-closures on a two-lane freeway, the MUTCD recommends the use of the right lane closure shown in Figure 8 whereas, the left lane closure, which is essentially the mirror image of this illustration, is also used by many jurisdictions in the U.S. However, it is believed that the right lane closure appears to be safer than the left lane closure; in the left lane closure setup, vehicles in the acceleration lane will need to decelerate to match the average operating speeds in the deceleration lane on the right. The safety implications of both of these methods have been displayed by Zhu and Saccomonno (*5*) in their study.

Many studies (*31*-*35*) in the past have shown that crash rates are generally higher in highways with work zones than those without. It was found that the presence of work zones not only causes congested traffic conditions, but creates potential safety hazards to motorists. There are many factors that may influence the crash rate in work zones such as geometry, pavement conditions, traffic volume, and weather. It is believed that lane closure strategy may be another factor that can influence the crash rate in highway work zones. Pal and Sinha (*36*) have conducted research to examine the effect of lane closure strategies and theirs crash potential in work zones in Indiana. In this research, two main lane closure strategies that were used in the project sites of the resurfacing, restoration, rehabilitation, and reconstruction (4R) program in Indiana were examined: crossover and partial lane closure (left or right lane closure).

In a crossover setup (also known as two-lane, two way operation), the traffic on one direction of the highway is closed for construction activities, while two-way traffic is maintained side-by-side on the opposite lanes by rerouting the traffic using the crossovers. Figure 9 shows the two-lane, two-way operation described. Generally, concrete barriers are used as a safety measure to separate the rerouted traffic traveling in opposite directions, as no other sufficient median device is available to protect drivers from high speed head-to-head traffic. Unlike the crossovers, one or more lanes in the partial lane closure setup are closed in one or both directions, but all of the lanes in one direction are not closed at any time. In this setup, however, the passing vehicles are very near the construction crew and equipment, and thus construction workers in the work area may be endangered by the proximity of passing traffic.

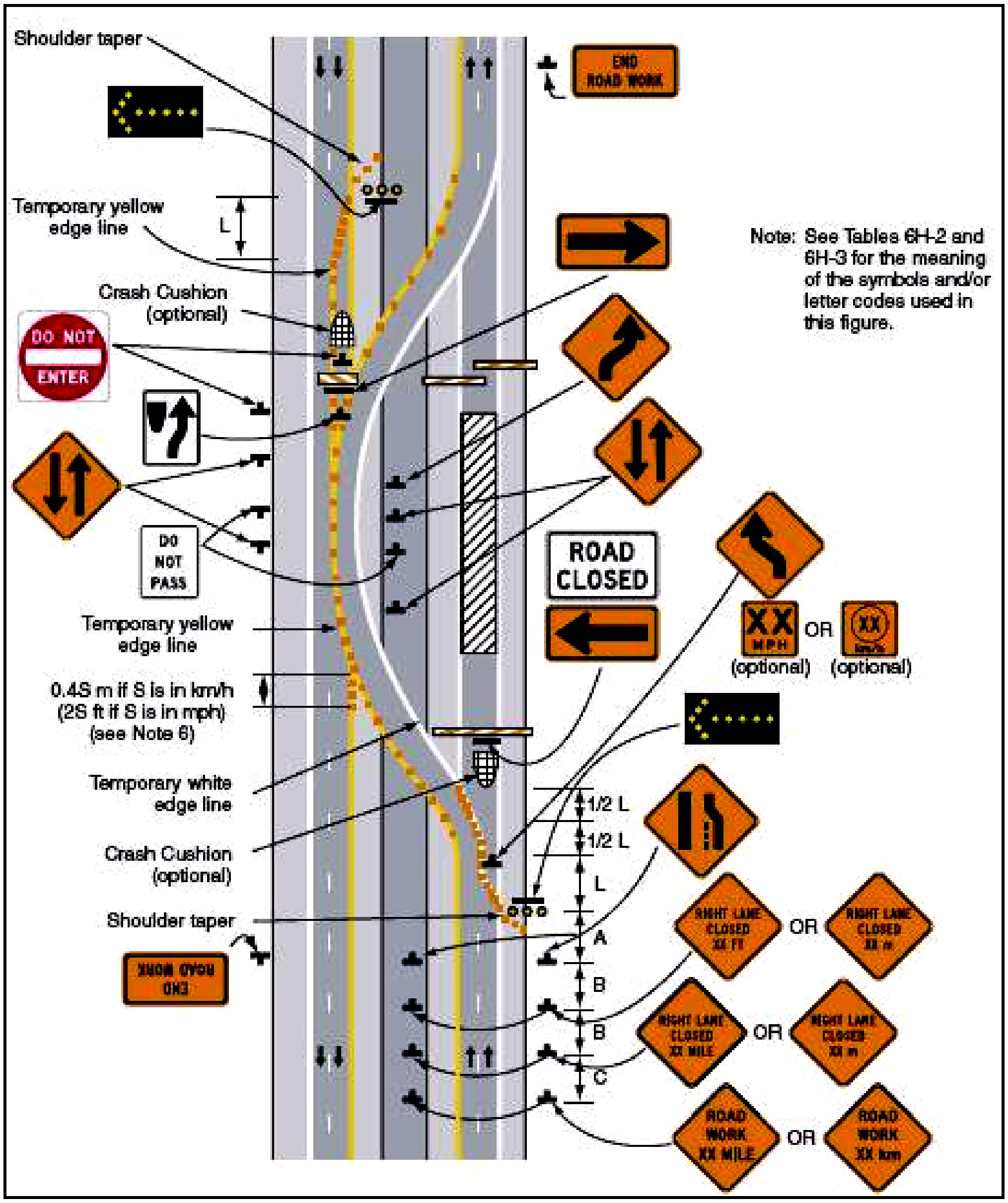


Figure 9 Median crossover on freeway (*29*)

In the research by Pal and Sinha (*36*), the before-and-after study with a comparison group and a check for comparability was chosen as the desired statistical method to conduct the study as it checks the compatibility of the comparison section in addition to examining the safety impact of a treatment. Prior to the selection, it was found that the empirical Bayes method is a desirable statistical procedure to analyze crash data as it increases the precision of estimates and corrects the regression-to-mean bias. However, the empirical Bayes method was not used in this research due to the sparsity of data and it was assumed that the regression-to-the-mean effect would not be significant as the project sites selected were not necessarily highway sections with high crash rates.

For the data analyses, the crashes from 1988 through 1993 that occurred at mile markers where the crossover and partial lane closure were set up were retrieved from the state police record. These crashes were categorized into three main categories for the statistical procedures: fatal, non-fatal injury, and property damage. The results of the analyses showed that the average crash rate at work zones was significantly higher than in normal operations where there were no work zones. It was also found that the average crash rate in a crossover setup was not significantly higher than in a partial lane closure setting. In their conclusion, Pal and Sinha recommended state agencies create extensive databases on crashes so that more sophisticated models can be developed in the future.

2.3.2 Work Zone Analysis

Congestion in work zones has been a major concern for state transportation agencies and local authorities. In some metropolitan areas, the traffic volumes have reached such levels that a relatively minor accident in a work zone can cause substantial delays to motorists and virtually paralyze the traffic during the peak period. The congestion issue that causes unproductive and wasteful delays may also result in hazardous conditions to motorists, where stopped vehicles in queue are approached by high speed vehicles upstream. In order to address this issue, Maze, Schrock and Kamyab (*37*) conducted a study to examine the volume that can pass through a work zone lane closure prior to and during congested periods on rural Iowa interstate highways to identify related driver behaviors. The authors explained that the purpose of this research was to determine the rates when the queue grows and when it decreases in length. The key findings of this research include: 1) the capacities in rural Iowa work zone lane closures varied from approximately 1,400 passenger car equivalents per hour to 1,600; 2) queuing vehicles at lane closures presents a safety concern as the through queues can move backward and forward at very fast rates; 3) the consistency in the data collection meant that a historical database can be developed to predict the likelihood of congestion and implement appropriate strategies to mitigate it. These possible strategies include determining alternative routes and informing motorists well in advance.

Generally, work zone lane closures are only allowed during peak periods when reserve capacity is available. Nonetheless, in some instances, where surges of traffic exceed beyond the capacity of a work zone, the removal of a lane closure may be required to alleviate the unexpected travel delays. In addition, some agencies may resort to closing the lane earlier than the scheduled date to take advantage of an extended work period. In order to better understand the risks associated with lane closures, Kononov and Znamenacek (*38*) conducted a quantitative risk analysis to compare the savings in the cost of construction in allowing the use of lane closure during peak periods, and the cost of incident-related delays in Denver, Colorado. The key findings of this research include:

- The authors stated that it is critical to assess the delay resulting from potential crashes before deciding on allowing the use of a lane closure during the peak period; the decision should not be solely based on the available capacity.
- The probability of delays and backups occurring at least once is as high as 93.5 percent during a typical construction project that requires a lane closure.
- The authors recommended the use of a sensitivity analysis to examine the risk of potential crashes as it is not ascertained to assess safety performance characteristics such as increased number of accidents and its magnitude of increase.

- Based on the case example, cost of allowing a lane closure during a peak period was $305,000 whereas, the premium that state DOT can incur if work was allowed only at off-peak was $150,000.
- The net societal disbenefits of allowing work during the peak period was $155,000.
- Work zone lane closure during the peak period should be avoided on urban freeways whenever possible considering the secondary adverse impact such as driver frustration and negative public relations.

The accuracy of estimates in safety assessment has always been a top priority among traffic safety researchers. However, without accurate data it is impossible to know whether the estimates in the performance measures are reflecting the true changes in the assessment or changes in external factors. Prior to 2004, the issue described was a concern for work zone exposure characteristics as there was no comprehensive data on the subject matter at the national level to aid researchers in calibrating their results. In 2004, these tasks were made possible for researchers when Ullman, et al. (*39*) conducted a study to explore the quality and quantity of available work zone data in the U.S. The methodology of this research included: 1) gathering and reviewing data in five regions of the country; 2) extrapolating the regional data to create the national estimates of several work zone exposure characteristics on the National Highway System (NHS); 3) examining project diaries, traffic control plans, and construction management databases on projects undertaken by private contractors in these regions; 4) collecting and examining data on work zone activities that were performed by transportation agency personnel in each region. The following are the key findings of this research:

- Authors estimated that 26.5 percent of the NHS (combined average of the five regions nationally) or 43,500 route miles experienced work activity of at least 1 day during 2001.
- The average work zone contract length was extrapolated to be 5.0 mi, whereas the actual work area within that project length was found to be 1.5 mi each day.
- Authors found that July 25, 2001 was the date of peak work activity for 2001 on the NHS. 4.8 percent of the NHS (or approximately 7,900 route miles) experienced some work activity on that day while, 3.1 percent of the NHS (or approximately 5,100 route miles) experienced an inactive work zone on that day.
- Contract work zones had work activity take place within their project limits 3.5 times per week annually. This equates to 50 percent of all calendar days for a work zone contract (or approximately 77 percent of the five-day work week excluding holidays).
- Authors found that "lane and shoulder closures accounted for a capacity loss of 41 million vehicles per day on the NHS on the peak day" (or 4,370 lane miles over the period of a typical work shift on a

typical work day), which “equates to a capacity loss of over 8.1 billion vehicles on the NHS during the entire calendar year.”

- Authors estimated that “approximately 1 percent of the vehicle miles traveled (VMT) on the NHS (or 12 billion vehicle miles) passed an active work zone in 2001.”
- Authors found that “nearly 5 percent of the VMT on the NHS (or 61 billion vehicle miles) passed an inactive work zone.”
- Authors estimated that “approximately 0.4 percent of the VMT on the NHS (5 billion VMT) occurred past inactive work zones where a lane closure had been left in place.”

The increase in miles traveled and number of work zones on the roadway are two main findings that have been constantly linked with the rise in the work zone fatality rate. However, the numbers and percentages found in those work zone fatality rates often do not reflect the actual causal factors. Numerous studies in the past have attempted to identify those contributing factors to the work zone fatality rate. In 2000, Daniel, Dixon and Jared (*40*) reported the results of an analysis of fatal crashes at work zone locations in Georgia. This study was initially conducted for the Georgia Department of Transportation to examine the location, manner of collision, and construction activities that are associated with fatal crashes in work zones but was further expanded to compare the fatal crashes in work zones and non-work zone locations. The overall findings of this research showed that: 1) “work zones influence the manner of collision, light conditions, truck involvement, and roadway functional classification under which fatal crashes occur"; 2) fatal non-work zone crashes are less likely to involve another vehicle than work zone crashes; 3) fatal non-work zone crashes are more likely to be influenced by horizontal and vertical alignment than work zone crashes.

A similar fatality analysis was also carried out by the TTI in 2004. In this research, Schrock, et al. (*41*) developed a new methodology that used site reviews and narrative descriptions to examine crashes in Texas. The approach of this methodology adopted the practices of the Fatality Assessment and Control Evaluation (FACE) Program, to examine the work zone configuration and characteristics, which are generally not made available through crash database and police records. The key findings of this fatality analysis showed that:

- Less than eight percent of the examined accidents had a direct effect from the work zone;
- About four percent of the accidents involved highway personnel during traffic control installation or removal (or more than 40 percent of the total worker fatalities examined);
- Approximately 39 percent of the examined accidents had an indirect effect from the work zone; and
- About 45 percent of the examined accidents had no influence from the work zone (including 16 percent which happened in work zones that

were work zones in name only, where only project limit signs were present at the time of the crash).

2.4 Summary of Literature Review

For this thesis research, a comprehensive literature review was undertaken to synthesize the background knowledge from previous studies. Table 6 shows the key findings of the literature review described.

Table 6 Key Findings of Literature Review

Subject	No.	Study	Location	Reference
Characteristics and effectiveness of Iowa weave (IW)	1	Safety evaluation of IW	Iowa	Brewer 1972
	2	Effectiveness of IW	North Carolina	Lorscheider & Dixon 1995
	3	Safety implications of IW	Ontario	Zhu & Saccomanno 2004
Work zone (WZ) Lane Closure	4	Lane closure strategies	Indiana	Pal & Sinha 1996

The results of the literature review are summarized as follows:

- Brewer (*3*) found that the Iowa weave pattern was highly effective in construction sites, with more than 50 percent of all vehicles sampled traveling below the posted temporary speed limit of 30 mph. Whereas in construction sites where the forced weaving was not used, the posted speed limit compliance of all vehicles sampled was found to be less than 20 percent. The author concluded that no excessive driver confusion was found in the use of this weave pattern, even though three vehicles were found performing unusual maneuvers in the advance warning area.

- Lorscheider and Dixon (*4*) found that this weave pattern was effective in reducing the speeds of motorists in work zones despite the finding that it increased driver confusion in the urban settings. Therefore, they recommended this weave pattern should be limited to rural freeways, where it is most effective in reducing speeds. The authors concluded the study that the Iowa weave can be a great time saver method for contractors in construction work zones even though "numerous" drivers were confused by the direction of the advance signs that led them to the lane that was closed.
- The simulation results of Zhu and Saccomanno's (*5*) research found that the right-hand closure appeared to be safer than the left-hand closure, whereas the proposed layout on a three-lane freeway segment (or the Iowa weave) was found to be safer than both the left-hand closure and right-hand lane closure. The authors explained that the proposed layout helps to avoid high-risk lane changing that could occur on the higher-speed left lane than the lower-speed right lane.
- The results of Pal and Sinha's (*36*) analyses showed that the average crash rate at work zones was significantly higher than in normal operations where there were no work zones. The authors also found

that the average crash rate in a crossover setup was not significantly higher than in a partial lane closure setting (left or right lane closure).

Chapter 3: Data Collection and Reduction

This study focused on the fatal and injury crashes that occurred in Arkansas highway work zones from January 1, 2000 through December 31, 2005. The data for the crash model development were extracted from the AHTD, obtained from the Planning and Research Division. This database contains the details of all the police reported crashes in Arkansas IRP work zones available in two subfiles (Accident File and Vehicle File). In addition, construction diaries and plans involving both the Iowa weave and conventional setting (or the right lane closure) during the IRP were duplicated in order to determine the lane closure settings at each project site. In order to maintain the accuracy in the data, the crash data were carefully examined by coding the response variables in two binary values (0 and 1) in a spreadsheet before feeding it to the SPSS analysis tool.

3.1 Data Collection and Reduction Procedure

3.1.1 Data Sources and Collection

A total of 54 project diaries and plans were obtained from the AHTD, including two projects that performed the conventional setting (or the right lane closure) only. These two projects, however, were not considered in the selection process in order to prevent bias in the data. Another four projects, which were identified as technology enhancement (or non-lane closure involved) projects by the AHTD, were not collected for this research. As the first step of the data reduction procedure, the construction plans of the remaining 48 projects were scrutinized to ensure that lane closures-related information was available. This measure was intended to eliminate unnecessary data details that may have led to inaccuracies in the analyses, and ensure that locating and determining the lane closure setup was possible. After careful examination of the plans, 24 projects were identified and removed from the project pool. The following are the descriptions of the projects that were removed from the project pool:

- Projects that used the conventional traffic control plans only (note: these projects were designed and planned before the inclusion of the Iowa weave in the AHTD's specifications);
- Bridges or interchange projects due to the short distances involved;
- Three-lane interstate freeways in an urban setting, where two lanes were open instead of one lane;
- The interstate in question had only one IRP project (e.g. I-540 had only one project) and was removed to prevent any bias that might be specific with that roadway;
- Mile markers or the log miles were not available, thus locating the work zone was not possible;
- Traffic control plans did not have information on the weave pattern (due to change orders); and

- Technology enhancement projects (note: the work was done on the side of the road and no lane closures were involved).

3.1.2 Data Reduction Procedure

Through the selection process, a total of 24 out of the 54 IRP projects were chosen for the data analyses, including 17 projects that used the median crossovers. These projects were identified as follows:

Table 7 Project Information by Date and Mile Marker

No.	Project No.	Interstate Route	Work Start Date	Estimated Completion Date	Start Mile	End Mile	Total Distance
1	B80105	I-40	2/20/2000	10/1/2002	83.64	94.52	10.88
2	B10100	I-40	7/7/2000	9/1/2001	228.2	239.82	11.62
3	B40103	I-40	1/19/2001	12/1/2001	31.09	38.36	7.27
4	BX0100	I-30	1/19/2001	12/1/2001	51.41	56.41	5.00
5	B30100	I-30	1/22/2001	9/1/2001	36.69	44.46	7.77
6	B10107	I-55	2/28/2001	5/1/2001	15.1	23.13	8.03
7	BX0102	I-30	3/5/2001	10/1/2002	77.97	85.96	7.99
8	B60105	I-40	3/19/2001	6/1/2003	154.81	163.81	9.00
9	B80103	I-40	4/17/2001	9/1/2004	53.5	59.61	6.11
10	B40105	I-40	5/23/2001	10/1/2002	17.05	24.49	7.44
11	BX0101	I-55	5/30/2001	5/1/2003	23.08	35.05	11.97
12	B80104	I-40	5/30/2001	6/1/2002	71.51	76.85	5.34
13	B80107	I-40	5/30/2001	6/1/2002	118.96	124.34	5.38
14	B80106	I-40	7/5/2001	9/1/2003	101.15	113.15	12.00
15	B10102	I-40	7/5/2001	11/1/2002	216.58	228.2	11.62
16	B00100	I-55	7/6/2001	8/1/2003	52.38	58	5.62
17	B60106	I-40	7/24/2001	6/1/2003	181.6	194.39	12.79
18	B10103	I-40	9/10/2001	6/1/2003	264.57	277.57	13.00
19	B60113	I-40	4/3/2002	12/1/2004	163.81	175.25	11.44
20	B40102	I-40	4/15/2002	2/1/2004	7.04	17.05	10.01
21	B80108	I-40	4/18/2002	9/1/2004	63.67	71.51	7.84
22	B10106	I-55	6/9/2003	10/1/2004	4.59	0.81	3.78
23	B80110	I-40	7/9/2003	11/1/2004	124.37	135.65	11.28
24	B10104	I-40	7/23/2003	9/1/2004	248.1	264.57	16.47

Initial efforts in determining the lane closure setup revealed that detailed observations were required in order to accurately conclude the lane closure setup in each project. Hence, 11 out of the 24 projects were sampled using a random number generator (RNG). In addition, the lane closure setups were reviewed by another researcher other than the author to ensure that the accuracy and consistency in the data were well maintained. This measure was intended to examine whether the interpretation of the lane closures setup was accepted by a researcher other than the author and the AHTD. A total of 6,184 pages of construction diaries were reviewed through these 11 projects. Additionally, the language in the construction diaries was verified with the engineers in AHTD to mitigate any identification errors.

3.1.3 Data Sampling

The data sampling consists of two simple steps. First, the 24 projects were assigned with numbers as stated in Table 7. These numbers were assigned based on the work start dates provided by the AHTD. It was organized from the earliest work start date to the latest to ensure that these projects were not chosen from the similar IRP period and the projects were evenly distributed. As the second step of the data sampling, 11 projects were randomly selected through the RNG software. Furthermore, the “exclude duplicate numbers” (or the random without replacement) option in the RNG software was applied to ensure that there was no repetition in the selection of the projects.

Table 8 shows the descriptions of the RNG results generated. As shown in this table, the 11 projects consist of:

- Six projects on Interstate 40 (I-40),
- Three projects on Interstate 30 (I-30), and
- Two projects on Interstate 55 (I-55).

Table 8 Summary of the RNG Results

No.	Project No.	Interstate Route	Work Start Date	Estimated Completion Date	Start Mile	End Mile	Total Distance
4	BX0100	I-30	1/19/2001	12/1/2001	51.41	56.41	5.00
5	B30100	I-30	1/22/2001	9/1/2001	36.69	44.46	7.77
6	B10107	I-55	2/28/2001	5/1/2001	15.1	23.13	8.03
7	BX0102	I-30	3/5/2001	10/1/2002	77.97	85.96	7.99
9	B80103	I-40	4/17/2001	9/1/2004	53.5	59.61	6.11
10	B40105	I-40	5/23/2001	10/1/2002	17.05	24.49	7.44
11	BX0101	I-55	5/30/2001	5/1/2003	23.08	35.05	11.97
17	B60106	I-40	7/24/2001	6/1/2003	181.6	194.39	12.79
18	B10103	I-40	9/10/2001	6/1/2003	264.57	277.57	13.00
21	B80108	I-40	4/18/2002	9/1/2004	63.67	71.51	7.84
24	B10104	I-40	7/23/2003	9/1/2004	248.1	264.57	16.47

3.1.4 Selection of Projects

For the purpose of this study, the tapers of the Iowa weave and conventional setting (or the right lane closure) in the merging area were assumed to remain in the same location throughout the project duration unless otherwise indicated in the construction diaries. In addition, lane closures of projects that detour the traffic to another route other than the interstates were not considered in this research. During the data reduction procedure, it was found that the projects may consist of more than a pair of median crossovers. In order to maintain the consistency in the data, these projects were not selected to prevent extraneous details such as sophisticated lane closure setups. Furthermore, determining the lane closure setup of such complex settings required additional time, resources and efforts, yet the results may not be extremely useful in the latter stages of the research. Scrutiny of each selected project, and its construction diaries and plans indicated that project B10103 comprised of three pairs of median crossovers throughout the project limit. This project was not selected and thus reduced the total number of projects to ten.

Other than time, resources and efforts, the determination of lane closure setup required detailed observations and, most importantly, technical judgment. Because the data were not in a format that can be readily fed into the statistical software such as the SPSS, the lane closure settings needed to be accurately identified through the construction diaries and plans before it could be incorporated into the crash records. Initial observations of the plans and diaries showed that the documented lane closure information was not reliable, as the construction observers were likely to miss the opportunity to document the lane closure setups for a particular project. Moreover, the partial lane closure operations were considered routine work or incidental as compared to the median crossovers (or the two-way, two-lane operation). Thus, it may not be regarded as a major traffic operation that required detailed documentation on big projects, such as 10 miles, by the construction inspectors. In order to address the issue, the stationing and the work location (left or right lane) can be used as good indicators to determine whether the traffic was allowed on that lane. By examining the construction activities and the documented lane closure activities, the lane closure setups can be accurately determined and verified.

3.1.5 Work Zone Terminology

Similarly, like any other construction diaries, the terminologies and abbreviations in these documents needed to be familiarized before one can accurately interpret the activities. For the IRP, the AHTD used the left main lane (LML) and right main lane (RML) terminology as their main direction indicators for their projects. The nomenclature starts with the "ahead station," which is the lower station number of the project. The term "ahead station" is defined as looking ahead from a downstream location (or station). For instance, if the project limit was from station 900+00 to 1000+00, the "ahead station" for the project was situated at station 900+00. With the "ahead station," the LML and RML can be identified simply by judging from the downstream location, the lanes on the left are LML while the lanes on the right are RML. Figure 10 shows the LML and RML described.

While the LML and RML terminology were generally used in the diaries, conventional wisdom on direction (north, south, east, west) was not neglected by the construction observers. Conventionally, construction inspectors would use the terms east or westbound, or north or southbound in the diaries to indicate the direction of traffic. As the mile markers always get larger for the traffic heading east or north (*42*), it was found that the traffic direction of RML is always either eastbound or northbound depending on the direction of interstate. In contrast, the traffic direction of LML (opposing side) could either be westbound or southbound. Figure 10 shows the terminology described. Other than the main lanes (LML or RML), individual lanes on each side of the direction needed to be clearly stated in the diaries as well to indicate the work location. The left and right lanes were determined by using the "ahead station." Construction observers of AHTD used the terms "outside lane" or "inside lane" to indicate the work or lane closure location. For instance, left lane of LML also means outside lane of LML, whereas left lane of RML is the inside lane of RML. In essence, the lanes that were closer to the median were inside lanes, whereas the lanes adjacent to the shoulder were outside lanes. Figure 10 shows the nomenclature described.

As the median crossovers (or two-lane, two-way operation) received recognition for its advantages in time saving, the AHTD realized the importance of integrating this preeminent feature to ensure the projects were completed on schedule. Consequently, many of their IRP projects that were comprised of at least 5 miles or longer would always incorporate the use of median crossovers to shorten the work duration by reducing the indispensable time for lane closure setups and traffic switching. As described by Lorscheider and Dixon (*4*) in the literature, a lane closure involving an advance warning area on an urban freeway can take up to two hours to set up and remove. In order to overcome this, the AHTD combined the use of Iowa weave, conventional setting (or the right lane closure), and the median crossovers to minimize the time that would normally be allocated to set up and remove the lane closure settings. Figure 11 shows the median crossovers or TLTWO described.

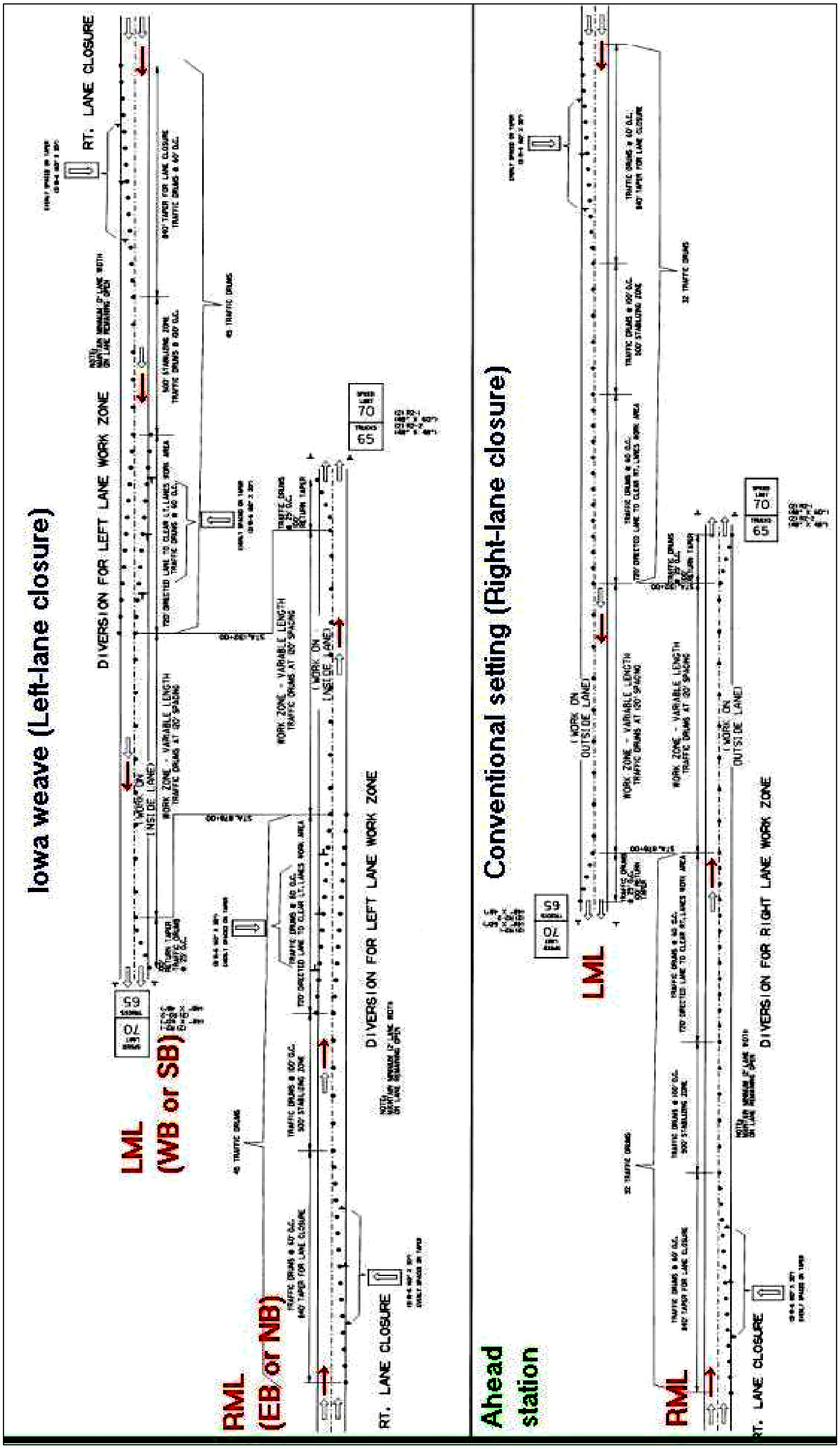


Figure 10 Iowa weave and conventional lane closure setting

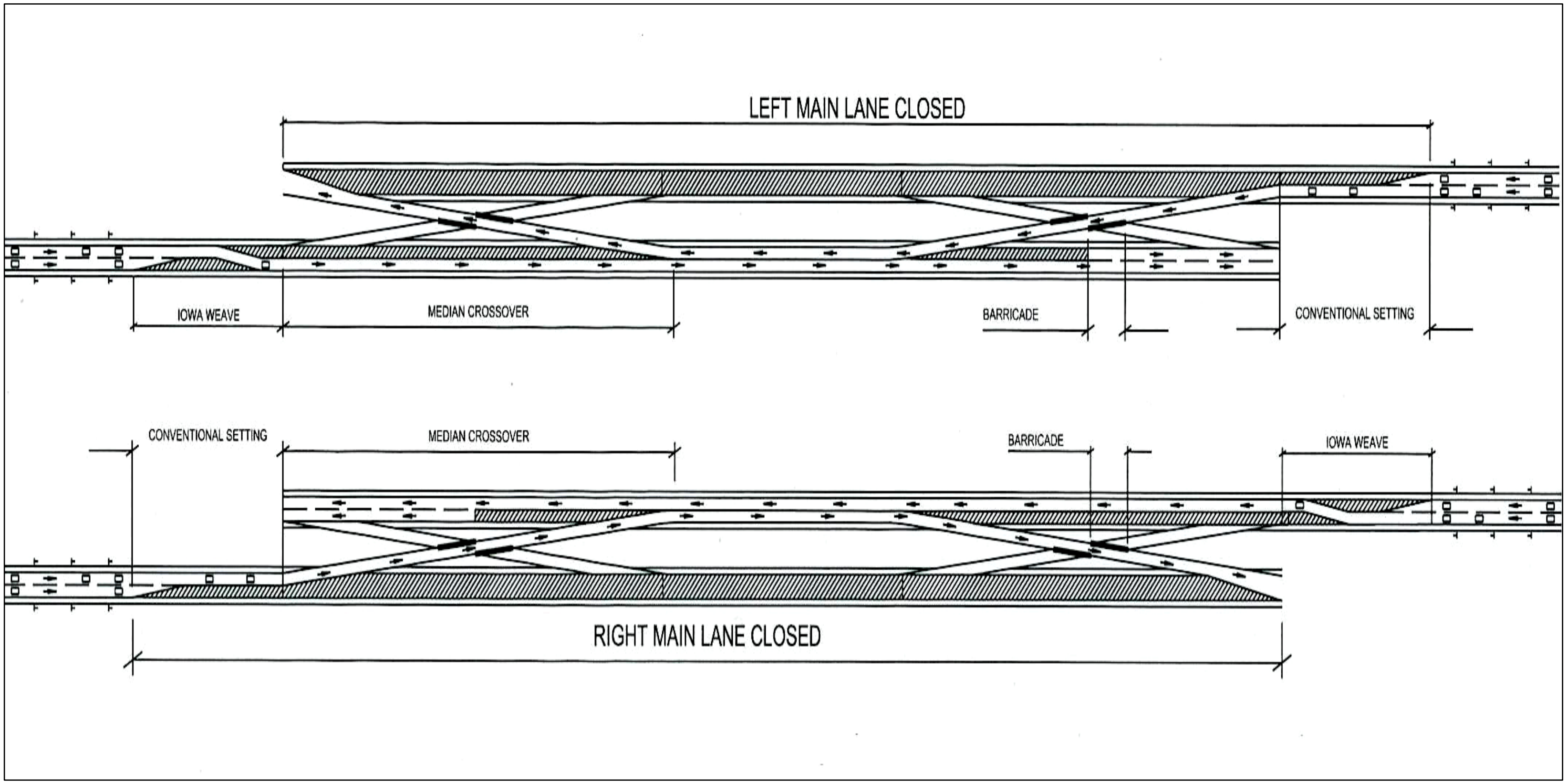


Figure 11 Iowa weave, conventional setting, and median crossovers

As observed in Figure 11, the traffic on one direction of the highway is closed for construction activities, while two-way traffic is maintained side-by-side on the opposite lanes by rerouting the traffic using the crossovers. In order for the traffic to maneuver safely into the median crossovers, this unique feature required the assistance of partial lane closures to merge the traffic into one single lane at the upstream location prior to reaching the median crossovers. Conventionally, left and right lane closures would be incorporated into the TLTWO before rerouting the traffic into the median crossovers. However, in Arkansas it is restricted to start with lane closures on the left and merge from left to right (from the high speed lane to the slow speed lane). The AHTD explained that this practice enables drivers to be better aware and more prepared for the lane drops ahead of them and avoid the uncertainty as to which lane will be closed. Furthermore, vehicles in the acceleration lane do not need to decelerate to match the average operating speeds in the deceleration lane on the right. Consequently, the Iowa weave is used as a substitute for the left lane closure in Arkansas. Figure 11 shows the use of Iowa weave and conventional setting (or the right lane closure) in TLTWO.

For the through traffic in TLTWO, the AHTD utilized the Iowa weave to converge the traffic into single lane at the upstream location whereas; the conventional setting (or the right lane closure) is set up at the similar upstream location on the opposite end to merge the maneuvering traffic. For example, if the LML was closed for the construction activities, the Iowa weave was placed on the upstream RML to merge the through traffic, while the conventional setting was installed at the upstream LML to converge the opposing traffic prior to maneuvering into the crossovers. Figure 11 shows the TLTWO described.

3.1.6 Crash Records

As the final step of the data preparation, the lane closure setups were incorporated into the crash record prior to the binary coding procedure. Due to the crash reporting methodology in Arkansas, a vehicle subfile was extracted from the AHTD in order to determine the vehicle direction of travel for each crash. The officials in the Planning and Research Division of AHTD explained that there is no data in the crash database to indicate a crash that occurred on a certain lane was heading to certain direction. Thus, if more than one vehicle were involved, the direction of travel for these vehicles was classified individually under the same crash number. In order to prevent repetition of crashes in the database, a separate vehicle subfile was created to identify the direction of travel for each vehicle. Upon verification of vehicle direction, the crash records were examined again by matching the dates, mile markers, and direction of the lane closure setups. In addition, any accident that was identified as a secondary crash was eliminated from the crash records to ensure that the selected crashes were independent.

For all of the lane closure, the stationing and the construction plans were scrutinized to identify the mile markers needed for each project. As the equivalency between stations and mile markers were clearly stated in each project plan, the task to convert them did not pose a significant problem. The only issue observed in this task was the accuracy of mile markers. It was found that the use of simple calculations could not justify the exact location of where the mile markers were situated. In order to mitigate the identification problem, the stationing and mile markers of both the work and lane closure limits were utilized to estimate the exact location of the area of interest (from the first barrel of the tapers to the last barrel of the weave section or tangent area). For instance, in the example of project B10107, the plans showed that the work limit was from station 620+00 (or logmile 15.10) to station 1044+24.9 (or logmile 23.13), whereas the lane closure limit was from 599+40 to 1064+84.9. As the distance of tapers, stabilizing zone, and weave section (or the tangent areas in the conventional setting) were known figures, the total distance was found to be 2,060 feet (or 0.39 mile). With that, the mile markers or the logmiles needed for the lane closure setting were calculated to be 14.71 (15.10 – 0.39 = 14.71) and 23.52 (23.13 + 0.39 = 23.52). These mile markers were calculated by examining the stations of work and lane closure limits. The following are the calculations described:

- 620+00 (logmile 15.10) - 2,060 feet = 599+40 (logmile needed or 14.71)
- 1044+24.9 (logmile 23.13) + 2,060 feet = 1064+84.9 (logmile needed or 23.52)

Table 9 shows the stationing and logmiles of the project described.

Table 9 Stationing and Logmile of Project B10107

Project No. B10107	Station/ Logmile	Lane Closure Limit	Tapers (feet)	Stabilizing Zone (feet)	Weave Section/ Tangent (feet)	Work Limit
North bound	Station	599+40	840	500	720	620+00
	Logmile	14.71[a]		0.39		15.1
South bound	Station	1064+84.9	840	500	720	1044+24.9
	Logmile	23.52[a]		0.39		23.13

[a] Logmiles needed

The calculation may not be applicable for all of the projects as the definitions of work and lane closure limits may be different. For example, the designer of the project may define the "lane closure limit" as the "work limit." Nonetheless, the basic principle of this methodology was consistently utilized by using the lane closure limits information in each project.

Over the 6-year period from 2000 to 2005 there were approximately 28,834 crashes (fatal, injury, and property damage only) that occurred on Interstates 30, 40, 55, and 540 in Arkansas. Initial efforts in the data reduction procedure showed that there were approximately 240 work zone crashes that occurred within the project areas. However, these crashes did not account for the underreporting issue. It is believed that the underreporting problem is significant whenever the police crash database is used. Ullman and Scriba (*43*) found that crash reports may "underreport the number of fatalities in work zones nationally by as much as 10%." In the crash database obtained from the AHTD, there are data to indicate whether there were construction activities underway on the highway. This information, however, was not taken into consideration when deciding whether a crash occurred in a work zone, as previous findings have showed that there is a statistically significant dependence between how work zones are denoted in state's crash report form and the number of fatalities that are recorded as occurring in a work zone (*43*). In order to prevent judgment errors that may be caused by the enforcement officers who completed the crash report, 0.25 mile (or 1,320 feet) was added on both the upstream and downstream locations of the study area. However, as mile markers are presented in tenths of a mile, the adjustment was rounded to 0.3 mile (or 1,584 feet) in order to be consistent. Upon revision of the methodology, 44 out of the 240 crashes were found to be within the study area. As the final task of the data reduction procedure, these crashes were scrutinized again before proceeding to the binary code procedure.

3.2 Identification of Variables Related to Iowa Weave

3.2.1 Research Datasets

As the final step in preparing the research datasets, the 44 crashes were programmed in a spreadsheet format prior to initiating the binary code procedure. This step was considered a precautionary measure to ensure that the compilation of each crash was completed accurately without missing any useful information. In addition, the task also allowed the examination of dummy variables instead of using the SPSS predictor to code the variables. Other than fatal, injury, and property damage only (PDO) crashes, other relevant data that were found in the crash records include:

- Atmosphere conditions (rain, snow or clear);

- Light conditions (daylight, dark, dawn or dusk);
- Rural or urban;
- Roadway alignment (straight or curved);
- Roadway profile (level, grade, hillcrest or unknown);
- At intersecting street (yes or no – on ramp or off ramp);
- Alcohol involved (yes or no); and
- Annual Average Daily Traffic, AADT (16,000 – 63,000 vehicles per day).

As observed from the list, nine independent variables including lane closure strategies (Iowa weave or right lane closure) were considered for the logistic modeling. Seven variables (atmosphere conditions, light conditions, rural or urban, roadway alignment, roadway profile, at intersecting street, and alcohol involved) were categorical or discrete, and the remaining one variable (AADT) was continuous. Based on the variables included in the Arkansas crash database, it was found that not all of them are closely related to lane closure strategies. In order to assure that the selected variables fulfill the rule of thumb for logistic models, i.e. to use a minimum of 10 events per predictor variable (EPV), while obtaining only the variables that related to lane closure strategies and work zone crashes (*36*,*40*), a frequency table was generated to examine the occurrences ensuring that the minimum number was met. Table 10 shows the frequency of the variables described.

Table 10 Frequency of Dependent and Independent Variables Considered in the Logistic Regression Modeling

Variable Name	Binary Response	Interpretation	Frequency
Fatal (Response)	0	Crash was not categorized as fatal crash	43
	1	Crash was categorized as fatal crash	1
Injury (Response)	0	Crash was not categorized as injury crash	30
	1	Crash was categorized as injury crash	14
Non-injury (PDO) (Response)	0	Crash was not categorized as non-injury or PDO crash	14
	1	Crash was categorized as non-injury crash	30
Ia_wve (Predictor)	0	Conventional setting was observed at crash location	27
	1	Iowa weave was observed at crash location	17
AcH_Invd (Predictor)	0	Driver not under alcohol influence	42
	1	Driver under alcohol influence	2
RnSnw_Wther (Predictor)	0	Good weather conditions	35
	1	Weather was not clear	9
Daylight (Predictor)	0	Crash was not during daylight	7
	1	Crash occurred during daylight conditions	37
Rural (Predictor)	0	Crash occurred in urban area	7
	1	Crash occurred in rural area	37
Cur_Algnmt (Predictor)	0	Straight alignment exists at crash location	36
	1	Curve alignment exists at crash location	8
Prfl_Nt_Lvl (Predictor)	0	Crash location was level	36
	1	Crash location was not level	8
Int_St (Predictor)	0	Crash was not at an intersecting street	37
	1	Crash occurred at an intersecting street	7
AADT (Predictor)	Continuous	Minimum average daily traffic	16,000
		Maximum average daily traffic	63,000

As shown in Table 10, only two events were observed in variable of AcH_Invd (alcohol involved). In order to prevent bias, this low-event variable was not further considered in the statistical analysis. Scrutiny of each variable and its frequency showed that only one fatal crash out of the total 44 crashes was observed in the data. Because there was only one fatal crash, it was grouped with injury crashes for this analysis. While for PDO crashes, response variable Non_injury was not considered in the modeling procedure due to the highly skewed underreporting issue. It is believed that the reported PDO crashes are likely to be those vehicles that were no longer drivable but no one was injured. Consequently, the presence and absence of the lane closure setup will not account for the change at which PDO crashes are underreported. However, the observed PDO crashes in this study were inadvertently included for the statistical procedure as the total number of PDO crashes in response variable of Injury (binary code 0) and Non_injury (binary code 1) were identical.

The low-event observation found in variables of Fatal crashes and Ach_Invd (alcohol involved) presented a preview of the results. Nonetheless, it is believed that the numbers of fatalities in work zone crashes are underreported by as much as 10 percent (*43*). Upon examination of the variables, six independent variables including the Iowa weave were found pertaining to the focus of this research (*19*,*36*,*40*) and thus were included for further consideration. The following shows the independent variables described:

- Ia_wve

  (binary response 1 = Iowa weave, binary response 0 = conventional setting);
- RnSnw_Wther

  (binary response 1 = rain and snow, binary response 0 = clear);
- Daylight

(binary response 1 = daylight, binary response 0 = dark, dawn or dusk);

- Cur_Algnmt

  (binary response 1 = curved, binary response 0 = straight);

- Int_St

  (binary response 1 = on ramp, off ramp, binary response 0 = none); and

- AADT

  (Annual Average Daily Traffic, 16,000 – 63,000 vehicles per day).

As aforementioned, a total of 44 crashes (fatal, injury, and PDO) were selected for the statistical analysis. In order to assure the stability of the model (a ratio of at least 10 events per predictor variable), a variable-selection procedure was undertaken to determine the significant factors that affect work zone crashes. For this procedure, bivariate analyses were utilized to assess the significant variable combinations: Pearson chi-square and one-way ANOVA tests. For each of the Pearson chi-square and one-way ANOVA tests, the hypotheses were as follows:

H_0: There is no difference between variables

H_A: There is difference between variables

Table 11 shows the results of the Pearson chi-square and one-way ANOVA tests described. As shown in this table, only two pairs of variables were statistically significant at α = 0.05: Injury - Rain snow weather, and Iowa weave – Rain snow weather. In addition, the results showed that Curve alignment - AADT (p-value 0.06) was weakly significant at the 0.05 level. In order to eliminate the strongly correlated variables, while reserving the variable (AADT) that can be related to lane closure strategies, curve alignment was chosen to be eliminated. In an effort to search for four significant variables including the Iowa weave, the fourth most significant pair from this variable-selection results was included for the statistical analysis: Iowa weave – Intersecting street (p-value = 0.149). In essence, all of the independent variables except for curve alignment were included for further examination in the modeling procedure. This measure was intended to examine the non-significant variables more closely as these variables may be associated to lane closure settings only in certain conditions defined by other factors. In other words, the direct impact of these variables may not be statistically significant enough to be detected through the Pearson chi-square and one-way ANOVA tests. The following shows the variables described:

- Ia_wve

  (binary response 1 = Iowa weave, binary response 0 = conventional setting);
- RnSnw_Wther

(binary response 1 = rain and snow, binary response 0 = clear);

- Daylight

  (binary response 1 = daylight, binary response 0 = dark, dawn or dusk);

- Int_St

  (binary response 1 = on ramp, off ramp, binary response 0 = none); and

- AADT

  (Annual Average Daily Traffic, 16,000 – 63,000 vehicles per day).

Table 11 Results of Variable-Selection Procedure

Procedure	Variables	Degree of Freedom	Value (*p*-value[a])	Sum of Squares
Pearson chi-square	Injury - Rain snow weather	1	5.280 (**0.022**)[b]	--
	Injury - Daylight	1	0.040 (0.841)	--
	Injury - Curve alignment	1	1.682 (0.195)	--
	Injury - Intersecting street	1	1.179 (0.277)	--
	Iowa weave – Rain snow weather	1	12.051 (**0.001**)[b]	--
	Iowa weave - Daylight	1	0.063 (0.803)	--
	Iowa weave - Curve alignment	1	0.767 (0.381)	--
	Iowa weave - Intersecting street	1	2.082 (**0.149**)	--
	Rain snow weather - Daylight	1	0.195 (0.659)	--
	Rain snow weather - Curve alignment	1	0.124 (0.725)	--
	Rain snow weather - Intersecting street	1	0.195 (0.659)	--
	Daylight - Curve alignment	1	0.604 (0.437)	--
	Daylight - Intersecting street	1	0.016 (0.898)	--
	Curve alignment - Intersecting street	1	0.604 (0.437)	--
One-way ANOVA	Injury - AADT	17	0.873 (0.607)	3.469
	Iowa weave - AADT	17	1.317 (0.257)	4.826
	Rain snow weather - AADT	17	1.057 (0.439)	2.925
	Daylight - AADT	17	0.741 (0.736)	1.922
	Curve alignment - AADT	17	1.953 (**0.060**)[c]	3.670
	Intersecting street - AADT	17	0.909 (0.572)	2.194

[a] Asymptotic *p* value

[b] Significant variables

[c] Weakly significant variables

3.3 Summary

The data collection procedure served as a key step towards the data analyses. The procedure can be broken into five categories:

- Data collection (obtained construction plans, diaries, crash record, and vehicle files from AHTD);
- Data sampling (randomly selected 11 out of the 24 IRP projects from the project pool);
- Data examination (determined the lane closure setups through the construction plans and diaries);
- Data reduction (incorporated the lane closure setups into the crash record); and
- Binary coding (programmed the response and predictor variables into binary codes).

A total of 44 crashes (fatal, injury, and PDO) were identified from the 11 IRP projects between January 1, 2000 and December 31, 2005. In order to assure that the selected variables fulfill the rule of thumb for logistic models, i.e. to use a minimum of 10 events per predictor variable, while obtaining only the variables that related to lane closure strategies and work zone crashes, a frequency table and bivariate analyses (Pearson chi-square and one-way ANOVA tests) were conducted to determine the significant factors. Consequently, five independent variables including the lane closure setups were chosen through the variable-selection procedure: Lane Closure Strategies, Rain Snow Weather, Annual Average Daily Traffic (AADT), Intersecting Street and Daylight. The final spreadsheet contained binary codes of the crash variables described. The next chapter presents the results of the logistic regression modeling.

Chapter 4: Work Zone Crash Analysis

4.1 Statistical Procedure

Over the years, two major statistical procedures have been frequently used for crash data analyses: Bayesian and non-Bayesian approach. The Bayesian approach can be broken into pure Bayesian and empirical Bayes methods (*16*), while the non-Bayesian approach can be divided into three different categories: before-and-after study, before-and-after study with yoked comparison, and before-and-after study with comparison and check for comparability (*10*). As the focus of this study was to analyze crashes during the IRP period, the non-Bayesian approach was not further considered as a viable statistical procedure. In addition, it was found that there were insufficient lane closure data available for the examination of the before-and-after effect on both of the lane closure strategies even if extended outside the 6-year IRP period.

As for the Bayesian approach, the empirical Bayes method was found to be a popular choice to analyze crash data as it takes care of the regression-to-the-mean effect (*16*). However, this statistical procedure was not used in this research as it was assumed that the regression-to-the-mean would not have a significant effect. The reason for this assumption was because the location of these IRP projects were chosen by the AHTD, and these locations were not necessarily sections with high crash rates. Furthermore, it was found that the regression-to-the-mean effect becomes insignificant when 3 or more years of accident data are evaluated at high accident sites (*18*).

Logistic regression is a suitable statistical procedure to predict the correlation between a set of independent variables and a dichotomous response variable or outcome (*21*). This method has been frequently used in traffic crash analyses to determine various influential factors in highway safety. Since the relationship between lane closure strategies and the explanatory factors in this study are not linear, logistic regression was determined to be the most suitable statistical procedure to identify the important factors. In addition, logistic regression, whose outcomes are of a discrete or categorical nature, can predict the probability of the event of interest, while estimating the direct impacts of each variable. Furthermore, the logit function of this statistical procedure has advantages of being able to be more easily interpreted. Consequently, logistic regression was chosen to be the most appropriate statistical procedure for this study to assess the correlation between the explanatory response and predictor variables, and crashes. In the binary response case, the logistic regression model has the following form:

$$\text{Logit}\ (p_i) = \log\ (p_i / 1 - p_i) = \alpha + \beta` X_i \qquad (44)$$

Where

p_i = prob ($y_i = y_i \mid X_i$ is response probability, and y_i is first order level of y;

α = intercept parameter;

$\beta`$ = vector of coefficient to be estimated; and

X_i = vector of explanatory variable.

4.2 Goodness-of-Fit Test

As the first step of the data analyses procedure, it was essential to examine the underlying distributions between injury vehicle crashes (fatal and injury), and the Iowa weave. In order to determine whether the crash distributions were different based on the presence and absence of the Iowa weave lane closure setup, the Pearson chi-square, and Likelihood Ratio chi-square tests were conducted to test the following hypotheses:

H_0: There is no difference in the number of fatal and injury crashes based on the presence and absence of the Iowa weave.

H_A: There is a difference in the number of fatal and injury crashes based on the presence and absence of the Iowa weave.

Table 12 Results of the Comparison Between Fatal and Injury Crashes Based on the Absence and Presence of the Iowa Weave

	Value	***df***	***p*-value**[a]
Pearson Chi-Square	0.074[b]	1	0.786
Likelihood Ratio Chi-Square	0.074	1	0.785
No. of Valid Cases	44		

[a] Asymptotic *p* value

[b] expected count less than 5

The comparison of the distributions of fatal and injury crashes based on the absence and presence of the Iowa weave is shown in Table 12. The results of the tests showed that the difference between the crash distributions was not statistically significant at $\alpha = 0.05$, and thus the null hypothesis was not rejected. Since there are many factors that can influence the crash rate in work zones, the results of the tests were neither new nor surprising considering that prior findings on the Iowa weave were identical (*5*). Nonetheless, it is believed that association between fatal and injury crashes, and the Iowa weave can be accurately identified when other variables are factored into the equation of logistic regression.

4.3 Crash Rate

Crash rates serve as an important tool to measure and identify safety hazards at a particular location. This measurement combines the accident frequency with vehicle exposure, or the traffic volumes observed to determine the rate in crashes per million entering vehicles (C/MEV) (*45*). The following is the equation of the crash rate calculation described.

$$R = \frac{A * 1{,}000{,}000}{V * T} \qquad (45)$$

Where: A = Average number of crashes at study location;

V = Volume in the study location, ADT or AADT; and

T = Time, number of days in the study period.

Other than estimating the correlation between the Iowa weave and conventional right-hand closure, crash data, and a set of variables, it was important to determine the crash rate of the Iowa weave as opposed to the conventional setting in order to measure the impact of each lane closure setup. For this research, the annual average daily traffic (AADT) maps of the selected projects were examined to identify the traffic volume of each crash location (*46*). Table 13 shows the traffic volume described. Scrutiny of each project and its crash rates showed that the crash rate of the Iowa weave (0.2204 C/MEV) was lower than the conventional setting (0.3173 C/MEV) by a margin of 0.097. Alternatively stated, the Iowa weave setup as opposed to the conventional setting had approximately 30 percent lower chance to be involved in a work zone crash. In essence, the Iowa weave setup was found to be substantially safer than the conventional right-lane closure based upon the crash rates obtained (*5*).

Table 13 Traffic Volume of Selected IRP Projects

Project No.	Interstate Route	Lane Closure Setting	No. of Crashes	Duration of Project (day)	AADT	Crash Rate (C/MEV)
BX0100	I-30	C I	0 0	316	23,000	0 0
B30100	I-30	C I	1 0	222	22,000	0.2048 0
B10107	I-55	C I	2 1	62	27,000	1.1947 0.5974
BX0102	I-30	C I	3 2	575	25,600	0.2038 0.1359
B80103	I-40	C I	1 1	545	20,550	0.0893 0.0893
BX0101	I-55	C I	5 5	701	25,300	0.2819 0.2819
B60106	I-40	C I	6 5	677	35,864	0.2471 0.2059
B80108	I-40	C I	4 1	867	20,120	0.2293 0.0573
B10104	I-40	C I	4 0	406	31,075	0.3170 0
B40105	I-40	C I	1 2	496	23,000	0.0877 0.1753
Total			44			

Average crash rate for Iowa weave = 0.2204 C/MEV
Average crash rate for conventional setting = 0.3173 C/MEV
Legend: C = conventional right lane closure
I = Iowa weave lane closure setup

Nonetheless, it was crucial to examine whether these crash rates were different based on the project duration and traffic volume. Thus, a paired t-test was conducted to test the following hypotheses:

H_0: There is no difference in the average crash rates of the Iowa weave and conventional setting.

H_A: The average crash rate of the Iowa weave is statistically less than that of a conventional setting.

Table 14 Result of Paired t-test: Comparison of Crash Rates Based on the Project Duration and Traffic Volume

	Paired Differences			t	df	*p*-value[a]
	Mean	Variance	Pearson Correlation			
Conventional	0.28556	0.11162	0.85022	2.045	9	0.036
Iowa Weave	0.1543	0.03346				

[a] One-Tailed

The results of the t-test (p-value = 0.036) showed that the difference between the average crash rates was statistically significant at the 0.05 level of significance and thus the null hypothesis was rejected. In essence, the p-value showed that the strength of evidence was statistically significant with 95 percent confidence given the alternative hypothesis that the Iowa weave has fewer injuries than the conventional setting (*5*). Since the p-value indicates that there is no difference, it can be determined that the results showed evidence that there was approximately 30 percent reduction in crash rate when the Iowa weave configuration was used.

4.4 Logistic Regression Model

4.4.1 Model Specification

As aforementioned, only two pairs of independent variables were found to be significant at the level of significance of 0.05. These variable combinations were:

- Injury - Rain snow weather (Pearson chi-square, p-value = 0.022)
- Iowa weave – Rain snow weather (Pearson chi-square, p-value = 0.001)

In an effort to obtain two more independent variables, the third (curve alignment - AADT, p-value = 0.06) and the fourth (Iowa weave – Intersecting street, p-value = 0.149) variable combinations with the next lowest p-values were included for further examination in the modeling procedure. As stated in the variable-selection procedure, this measure was to ensure that the non-significant variables were examined more closely, as the variables may be associated to lane closures only in certain conditions defined by other factors. In other words, the direct impact of these variables may not be statistically significant enough to be detected through the Pearson chi-square and one-way ANOVA tests. Scrutiny of the results found that curve alignment and AADT were strongly correlated. In order to prevent bias due to the unavailable information on interaction terms (weighted average between the strongly correlated independent variables); the variable curve alignment was chosen to be eliminated from the variable-selection procedure. The reason for this elimination was because examination of the construction plans showed that lane closures are less likely to be placed on curved highway sections, while sections of highway with higher traffic volume (AADT) are more prone to higher risk for work zone collisions.

Based on the variable-selection results, Injury (response) along with Iowa weave, AADT, Intersecting Street, and Rain Snow Weather (predictors) were identified as the most significant variables for the first logistic model. Table 15 shows the results of the first model described. As shown in this table, two different pseudo R^2 (goodness of fit of a model) were obtained through the logistic model: Cox and Snell, and Nagelkerke. The Cox and Snell R^2 are generally interpreted in multiple regressions. This R^2 is based on the "log likelihood for the model compared to the log likelihood for a baseline model (*21*)." Due to the categorical outcomes, Cox and Snell R^2 is considered as a conservative coefficient of determination as compared to its adjusted version, Nagelkerke R^2, as even a perfect model will not reach the theoretical maximum value of 1. For the purpose of this research, Nagelkerke R^2 was used as a measure to estimate the goodness of fit of the model on a scale of 0 to 1. Table 15 shows the results of the Nagelkerke R^2 described. Whereas for the classification table (model accuracy), this function analyzes how well the model correctly classifies the subjects where the predicted event was observed. Alternatively stated, the table shows the percentage of occurrences and non-occurrences correctly predicted. Table 16 shows the results of the classification for the first binary model.

Table 15 Classifications and R^2 for the Selected Binary Models

No.	Variable	$Pr>\chi^2$ (df)	Nagelkerke (Cox & Snell) R^2	Model Accuracy	Model Coeff., B	Sig.	Odds Ratio, Exp(B)
1	Ia_wve (1)	0.001[a] (4)	0.464[b] (0.331)	72.7%	-0.298	0.747	0.742
	AADT_K				0.180	0.051	1.197
	Int_St (1)				1.313	0.271	3.717
	RnSnw_Wther(1)				20.769	0.999	1E+009
	Constant				-26.999	0.998	0.00
2	Ia_wve (1)	0.003 (4)	0.434 (0.310)	75%	-0.299	0.745	0.742
	AADT_K				0.183	0.057	1.201
	RnSnw_Wther(1)				20.648	0.999	9E+008
	Daylight (1)				0.225	0.829	1.252
	Constant				-25.925	0.998	0.00
3	Ia_wve (1)	0.015 (4)	0.341 (0.244)	77.3%[c]	0.806	0.329	2.240
	AADT_K				0.197	0.036	1.217
	Int_St (1)				1.287	0.275	3.623
	Daylight (1)				0.381	0.698	1.463
	Constant				-7.866	0.007	0.000

[a] Most significant model (Probability > Chi-square)

[b] Highest Cox & Snell and Nagelkerke R^2

[c] Highest classification table

Table 16 Outcome for the First Binary Model (Model Accuracy)

Injury		Predicted		Total	Percentage correct
		No = 0	Yes = 1		
Observed	**No = 0**	26	4	30	86.7
	Yes = 1	8	6	14	42.9
Total		34	10	44	72.7

Model Accuracy = (26+6) x 100/44 = 72.7%

As observed in Table 15, a Nagelkerke R^2 and classification percentage of 0.464 and 72.7 were obtained through the first binary model. The results were considered somewhat satisfactory considering that there were many other variations in work zone crashes (*47*) during the IRP. However, the results of this first model showed that the model coefficient and odds ratio of variable, Rain Snow Weather were unusually high. Scrutiny of the data and the variable-selection procedure found that the strong correlation between variables, Iowa weave and Rain Snow Weather (Pearson chi-square, p-value = 0.001) may be the contributing factor to this phenomenon. Circumstantial observation of the construction diaries showed that the lane closures may be temporarily removed during these adverse weathers in order to encourage safe driving. In other words, there is an interaction term between these two variables that should to be weighted correctly whenever the Iowa weave and Rain Snow Weather are included in the model. In order to verify this error, a second model was generated by replacing the variable, Intersecting Street with Daylight. The Nagelkerke R^2 for this second model was reduced to 0.434 but the overall classification percentage was found increase to 75 percent. Similarly, the model coefficient and odds ratio for Rain Snow Weather were found to be unusually high, validating the speculated error in this independent variable.

In an effort to locate the best model, a third model was generated by replacing the variable Rain Snow Weather with Intersecting Street, and keeping the variable Daylight in the model. The results showed that Nagelkerke R^2 was reduced further to 0.341, but the classification percentage increased to a new high of 77.3 percent. Consequently, the third model is deemed to be the most accurate as all of the independent variables except for traffic volume (AADT_K) in these three models were identical; i.e. not statistically significant even though the Nagelkerke R^2 in the first model was found to be the highest. Table 15 shows the results of the three binary models described.

Logit equations for all three models can be written by using the parameter estimates from Table 15, as follows:

$$\text{Logit } P_1 = -26.999 - 0.298\,(\text{Ia\_wve}) + 0.180\,(\text{AADT\_K}) + 1.313\,(\text{Int\_St}) + 20.769\,(\text{RnSnw\_Wther})$$

$$\text{Logit } P_2 = -25.925 - 0.299\,(\text{Ia\_wve}) + 0.183\,(\text{AADT\_K}) + 20.648\,(\text{RnSnw\_Wther}) + 0.225\,(\text{Daylight})$$

$$\text{Logit } P_3 = -7.866 + 0.806\,(\text{Ia\_wve}) + 0.197\,(\text{AADT\_K}) + 1.287\,(\text{Int\_St}) + 0.381\,(\text{Daylight})$$

4.4.2 Model Coefficient and Odds Ratios

The results of the correlation for lane closure setups involved in fatal and injury crashes are presented in Table 17. The parameter estimates model summarized the effect of each predictor (Ia_wve, AADT_K, Int_St, and Daylight). The effect of variables is determined by the likelihood indicators (positive or negative sign) in the model coefficients. Parameters with positive coefficients indicate the increase likelihood of default variable (or binary coded with 1), while the negative coefficients in the parameters denote the decrease in likelihood (*21*). For instance, Ia_wve (or the Iowa weave) was coded as one of the default variables, the model coefficient (0.806) obtained denotes the increase in likelihood of this default variable.

Odds ratio is used to measure the effect of significant predictors on the response variable. In essence, odds ratio quantifies the likelihood of an outcome being increased if the value of independent variable is subjected to a unit increase (*21*). For example, the relative effect of the Iowa weave versus the conventional right-lane closure setup is exp (0.806) = 2.240. If significant, the odds ratio would indicate that the odds of a crash in an Iowa weave setup being severe (injury or fatal crash) are 2.24 times higher than the odds of a crash being severe in a conventional right-lane closure setting. However, because in this case the parameter was not significant, there is no evidence that the odds of a crash being severe are different based on both of the lane closure setups.

Table 17 Parameter Estimates: Model Coefficients and Odds Ratios

	Model Coeff. B	Estimated Standard Errors	df	Sig.	Odds Ratio Exp(B)	95.0% C.I. for Odds Ratio	
						Lower	Upper
Ia_wve (1)	0.806	0.826	1	0.329	2.240	0.444	11.304
AADT_K	0.197	0.094	1	0.036*	1.217	1.013	1.463
Daylight (1)	0.381	0.982	1	0.698	1.463	0.214	10.023
Int_St (1)	1.287	1.180	1	0.275	3.623	0.358	36.610
Constant	-7.866	2.932	1	0.007*	0.000	--	--

Dependent variable: injury crashes
-2 Log likelihood = 42.751
Cox & Snell R Square = 0.244
Nagelkerke R Square = 0.341
Probability > Chi-square = 0.015
*Significant coefficient at $\alpha = 0.05$

4.4.3 Results of the Logistic Models

Interpretation of the final binary model in Table 17 shows that the likelihood ratio test (Probability > Chi-square) has a p-value of 0.015 (4 degree of freedom), which indicates that the null hypothesis is rejected or significant information is provided by the variables. Thus, it can be concluded that the predictor variables in the model affect work zone crashes where lane closures (Iowa weave or conventional right-lane closure) were in place. Nonetheless, all of the predictors or independent variables in this model except for traffic volumes (AADT_K, p-value = 0.036) were not statistically significant at the 0.05 level of significance. The positive coefficient shown in variable AADT_K indicates those high traffic volumes increase the probability of having severe crash. The odds ratio of this variable shows that the odds of a crash in high traffic volume being severe (injury or fatal) are 1.217 times higher than the odds of a crash being severe in low traffic volume. Nonetheless, this likelihood may not be present only in work zones as non-work zone locations are equally likely of having severe crash in high traffic volume condition.

The result of the Iowa weave found in this model echoed the finding in the Pearson Chi-square test, which showed that the correlation between fatal or injury crashes, and the Iowa weave was not statistically significant. Similarly, the results of this final model showed that Daylight and Intersecting Street were not statistically correlated to fatal or injury crashes. Since the variable Intersecting street (p-value = 0.275) was the second highest significant predictor, it was desirable to discuss the model coefficient and odds ratio of this predictor even though it was not significant at the 0.05 level. If significant, the positive coefficient of the variable Intersecting Street would indicate that intersecting streets increase the probability of having severe crash. The odds ratio of this variable would show that the odds of a crash at intersecting streets being severe (injury or fatal) are 3.623 times higher than the odds of a crash being severe at non-intersecting streets. The intersecting streets included in the model can be either an on ramp or an off ramp. The interpretations of these intersecting streets were based on the best judgment of law enforcement officers who complete the crash report.

On the basis of the results of the binary logistic regression analysis for lane closure strategies (Iowa weave and conventional right-lane closure), the selected model format with the estimated coefficients would be:

$$\text{Logit } P_i = -7.866 + 0.197\ (\text{AADT\_K})$$

4.4.4 Model Estimation

Due to the nature of work zone crashes, the final binary model was not validated. As aforementioned, only 44 out of the total of 28,834 crashes between January 1, 2000 and December 31, 2005 were found to be within the study area. These low number of work zone crashes were limited, and thus the additional model was not validated. In addition, the non-existence of a prior model on the subject matter was another reason that made the validation task more difficult.

As a precautionary measure, the selected model was estimated by using the XLSTAT, statistical software for MS Excel. Table 18 through 21 shows the results of this model estimation procedure. As shown in Table 18, the -2 Log likelihood, Cox and Snell R^2, and Nagelkerke R^2 were identical to the values obtained in the SPSS statistical package: 42.751, 0.244 and 0.341. Consequently, it can be concluded that the final model generated through the SPSS statistical package was accurately executed without any errors.

Table 18 Goodness-of-Fit Statistics Using XLSTAT

Statistic	Independent	Full
Observations	44	44
Sum of weights	44.000	44.000
Degree of freedom	43	39
-2 Log(Likelihood)	55.043	42.751
R²(McFadden)	0.000	0.223
R²(Cox and Snell)	0.000	0.244
R²(Nagelkerke)	0.000	0.341
AIC	59.043	52.751
SBC	62.612	61.672
Iterations	0	6

Table 19 Test of the Null Hypothesis Using XLSTAT

Statistic	DF	Chi-square	Pr > Chi²
-2 Log(Likelihood)	4	12.292	0.015
Score	4	10.649	0.031
Wald	4	6.164	0.187

Table 20 Model Parameters Using XLSTAT

Source	Value	Standard error	Pr > Chi²	Wald Lower bound (95%)	Wald Upper bound (95%)
Intercept	-5.392	2.571	0.036	-10.430	-0.354
Ia_wve	-0.806	0.826	0.329	-2.425	0.813
AADT_K	0.197	0.094	0.036	0.013	0.381
Int_St	-1.287	1.180	0.275	-3.600	1.026
Daylight	-0.381	0.982	0.698	-2.305	1.544

Table 21 Classification Table for the Estimation Sample Using XLSTAT

from \ to	No = 0	Yes = 1	Total	% correct
No = 0	29	1	30	96.67%
Yes = 1	9	5	14	35.71%
Total	38	6	44	77.27%

4.5 Chapter Conclusion

In this chapter, a series of tests including the binary logistic regression modeling were evaluated to determine the correlation between lane closure setups (Iowa weave and conventional right-lane closure) and crashes with a set of independent variables. The evaluation was intended to provide valuable information for determining the lane closure setup that has an advantage on the basis of work zone crashes. Based on the results of the logistic regression analyses, all of the independent variables except for traffic volume were not statistically significant at the $\alpha = 0.05$ level of significance. Nonetheless, the results found that traffic volume had a significant effect on the probability of a crash being a fatal or injury crash. It was found that the odds of a crash in high traffic volume being severe (injury or fatal) are 1.217 times higher than the odds of a crash being severe in low traffic volume.

Although the results of the regression model were not significant, the examination of crash rates for both of the lane closure settings provided important information regarding the comparison between the two setups. The results of this examination showed that the Iowa weave setup as opposed to the conventional setting had an approximately 30 percent lower chance of being involved in a work zone crash at the 0.05 level of significance.

Chapter 5: Summary and Conclusion

5.1 Conclusion

Lane closures serve as an important traffic control device to protect construction workers while they are actively working in a work zone. The adoption of the Iowa weave by DOTs has shown that this weave pattern is effective in speeding up the construction progress but, most importantly, safe for drivers to maneuver through the work zones. The idea to switch between the two lane closures setups on a periodic basis was observed to be a concern especially when there are non-local drivers that drive past the Iowa weave on Interstate highways. Prior studies (*3*-*5*) on the Iowa weave each reiterated that this weave pattern is safe and effective. Nonetheless, actual crash experience is the best way to determine the safety deficiencies and causal effects of this weave pattern as opposed to the conventional right-lane closure. This study was aimed at obtaining valuable insights regarding the advantages of the Iowa weave as opposed to the conventional right-lane closure on the basis of actual crash experience.

Based on the results of the crash analysis, conclusions were drawn and are presented as follows:

- The result of the paired t-test (p-value = 0.036) was statistically significant at the 0.05 level of significance, which indicates that there was approximately 30 percent reduction in crash rate when the Iowa weave configuration was used.

- Based on the final results of the logistic regression model, the safety advantages between the Iowa weave and conventional right-lane closure in changing crash severity were not significant (p-value = 0.329).
- Traffic volume was found to be the parameter that most significantly affected crash severity in the logistic regression model.
- The odds ratio of traffic volume (AADT_K) shows that the odds of a crash in high traffic volume being severe (injury or fatal) are 1.217 times higher than the odds of a crash being severe in low traffic volume. However, this likelihood may not be present only in work zones as non-work zone locations are equally likely of having severe crash in high traffic volume condition.
- The effect of lighting conditions and intersecting streets on the severity of crashes were not significant.

Based on the results of the One-Way ANOVA test, curved alignment and traffic volume for the selected work zones in Arkansas may be related in some way. Nonetheless, further investigation is needed to examine the interaction as the determination of curved alignment was based on the judgment of police officers that recorded it. The results of the t-test showed that the difference between the average crash rates was statistically significant at the 0.05 level of significance, given the alternative hypothesis that the Iowa weave has fewer injuries than the conventional setting (*5*). Since the p-value indicates that there is no difference, it can be concluded that the results showed evidence that there was approximately 30 percent reduction in crash rate when the Iowa weave configuration was used.

5.2 Future Work

As in any research, more questions were raised than answered. Though substantial research has been presented in this study, there is still more that can be done to investigate the Iowa weave and all related variables. In continuing the research, it will be helpful to collect field data of the stabilizing zone and weave section of an Iowa weave in order to examine the driving behaviors and capacity. This measure is a positive step towards obtaining the real-time driving conditions of drivers that were not reported in the crash report. Additionally, the crash comparison between the Iowa weave and conventional left-hand closure can be explored in order to better understand the relationship. Future research may also focus on simulation study of TLTWO, Iowa weave and conventional right-lane closure as observations of the construction plans and diaries showed that there may be two pairs of active median crossovers on both ends of construction projects.

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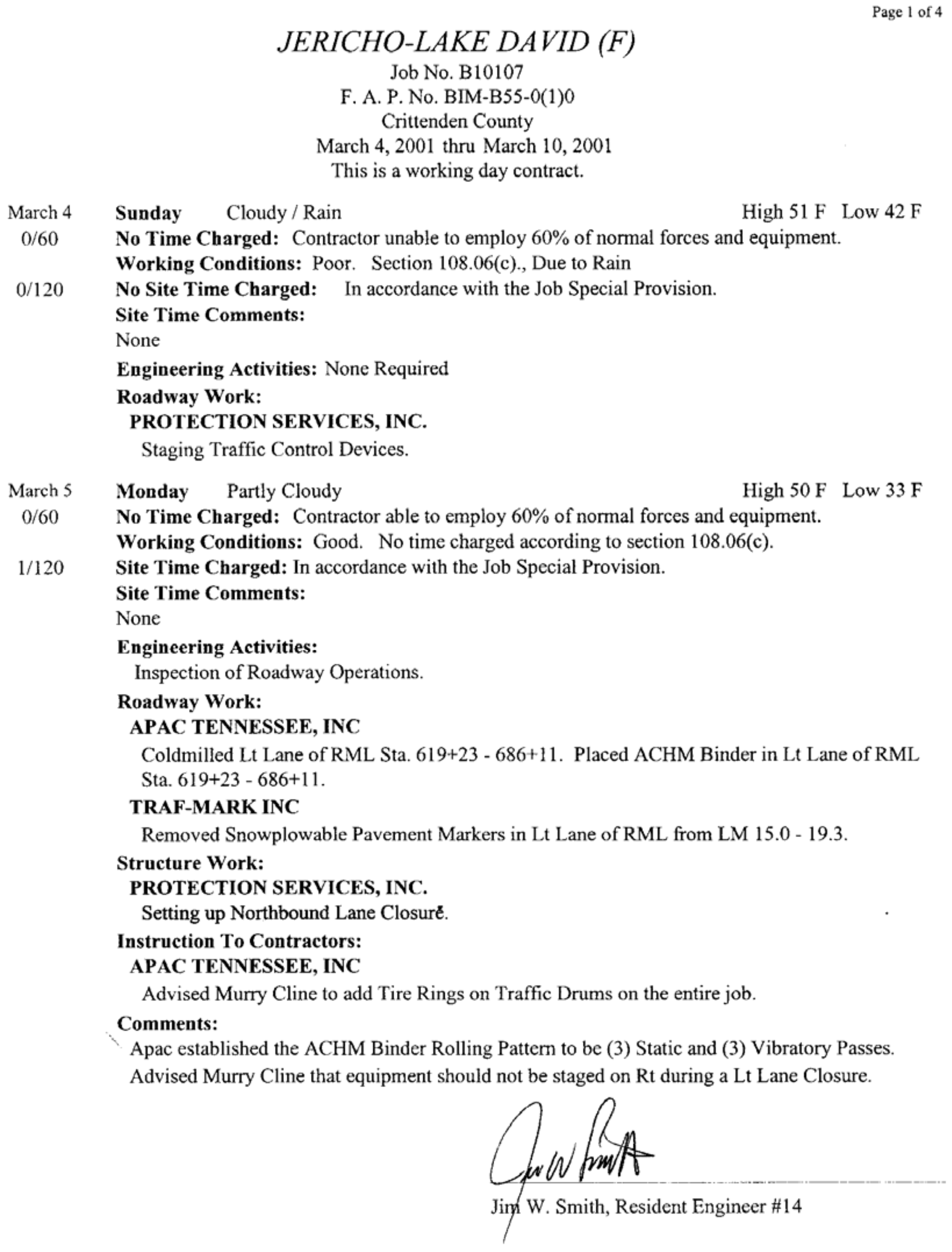
Appendices

Appendix A: Construction Diary Sample



Page 1 of 4

JERICHO-LAKE DAVID (F)

Job No. B10107
F. A. P. No. BIM-B55-0(1)0
Crittenden County
March 4, 2001 thru March 10, 2001
This is a working day contract.

March 4 **Sunday** Cloudy / Rain High 51 F Low 42 F

0/60 **No Time Charged:** Contractor unable to employ 60% of normal forces and equipment.

Working Conditions: Poor. Section 108.06(c)., Due to Rain

0/120 **No Site Time Charged:** In accordance with the Job Special Provision.

Site Time Comments:

None

Engineering Activities: None Required

Roadway Work:

PROTECTION SERVICES, INC.

Staging Traffic Control Devices.

March 5 **Monday** Partly Cloudy High 50 F Low 33 F

0/60 **No Time Charged:** Contractor able to employ 60% of normal forces and equipment.

Working Conditions: Good. No time charged according to section 108.06(c).

1/120 **Site Time Charged:** In accordance with the Job Special Provision.

Site Time Comments:

None

Engineering Activities:

Inspection of Roadway Operations.

Roadway Work:

APAC TENNESSEE, INC

Coldmilled Lt Lane of RML Sta. 619+23 - 686+11. Placed ACHM Binder in Lt Lane of RML Sta. 619+23 - 686+11.

TRAF-MARK INC

Removed Snowplowable Pavement Markers in Lt Lane of RML from LM 15.0 - 19.3.

Structure Work:

PROTECTION SERVICES, INC.

Setting up Northbound Lane Closure.

Instruction To Contractors:

APAC TENNESSEE, INC

Advised Murry Cline to add Tire Rings on Traffic Drums on the entire job.

Comments:

Apac established the ACHM Binder Rolling Pattern to be (3) Static and (3) Vibratory Passes.
Advised Murry Cline that equipment should not be staged on Rt during a Lt Lane Closure.

Jim W. Smith, Resident Engineer #14

March 6 **Tuesday** Partly Cloudy High 50 F Low 33 F

0/60 **No Time Charged:** Contractor able to employ 60% of normal forces and equipment.

Working Conditions: Good. No time charged according to section 108.06(c).

2/120 **Site Time Charged:** In accordance with the Job Special Provision.

Site Time Comments:

None

Engineering Activities:

Inspection of Roadway Operations. (DGH)

Roadway Work:

APAC TENNESSEE, INC

Coldmilled Lt Shoulder of RML Sta. 619+23 - 686+11 and Lt Lane of RML Sta. 686+11 - 764+46. Placed ACHM Binder in Lt Lane of RML Sta. 686+11 - 757+88.

PROTECTION SERVICES, INC.

Staging Southbound Lane Closure.

Instruction To Contractors:

PROTECTION SERVICES, INC.

Advised Gerald Banks to place a 250 Ft. Buffer Zone after the Iowa Weave and before the beginning of the work zone.

Comments:

Apac established the ACHM Surface Rolling Pattern to be (4) Static and (2) Vibratory Passes.

Murry Cline Advised this office that ACHM Surface Paving would be performed at night from 5 P.M. - 4 A.M. on Wednesday, Thursday and Friday. Milling at night and Binder during the day will continue as planned.

March 7 **Wednesday** Partly Cloudy High 57 F Low 33 F

0/60 **No Time Charged:** Contractor able to employ 60% of normal forces and equipment.

Working Conditions: Good. No time charged according to section 108.06(c).

3/120 **Site Time Charged:** In accordance with the Job Special Provision.

Site Time Comments:

None

Engineering Activities:

Inspection of Roadway Operations. (DGH)

Roadway Work:

APAC TENNESSEE, INC

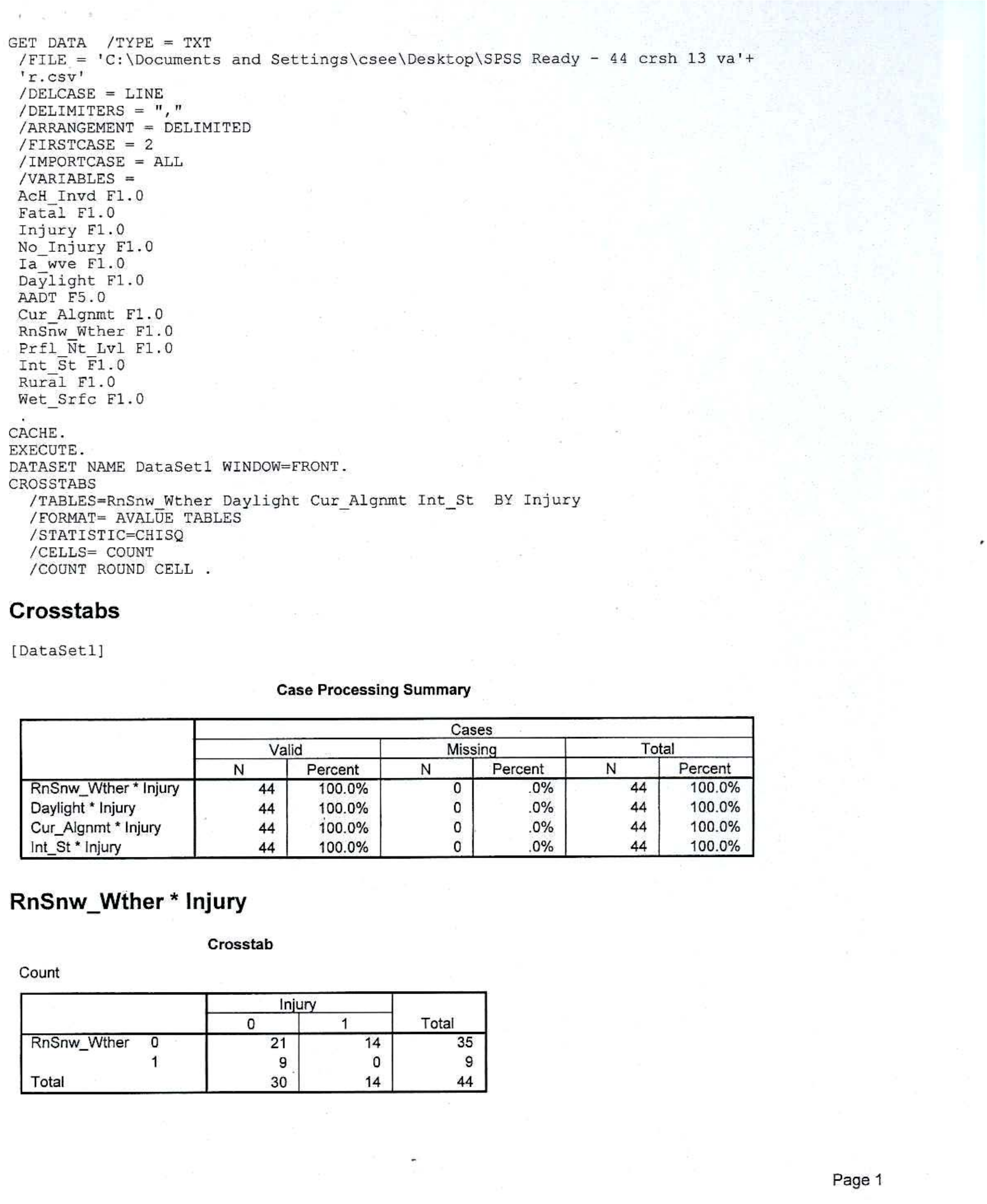
Coldmilled Lt Shoulder of RML Sta. 686+11 - 757+50 and Lt Lane of RML Sta. 764+46 - 840+55. Placed ACHM Binder in Lt Lane of RML Sta. 686+11 - 757+88 - 840+55 and ACHM Surface in Lt Lane & Lt Shoulder of RML Sta. 619+23 - 718+41.

PROTECTION SERVICES, INC.

Set up Southbound Lane Closure of Rt Lane LM 15.1 - 19.3.

Jim W. Smith, Resident Engineer #14

Appendix B: Pearson Chi-Square Tests



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 /IMPORTCASE = ALL
 /VARIABLES =
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 Fatal F1.0
 Injury F1.0
 No_Injury F1.0
 Ia_wve F1.0
 Daylight F1.0
 AADT F5.0
 Cur_Algnmt F1.0
 RnSnw_Wther F1.0
 Prfl_Nt_Lvl F1.0
 Int_St F1.0
 Rural F1.0
 Wet_Srfc F1.0
 .
CACHE.
EXECUTE.
DATASET NAME DataSet1 WINDOW=FRONT.
CROSSTABS
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  /FORMAT= AVALUE TABLES
  /STATISTIC=CHISQ
  /CELLS= COUNT
  /COUNT ROUND CELL .
```

Crosstabs

[DataSet1]

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
RnSnw_Wther * Injury	44	100.0%	0	.0%	44	100.0%
Daylight * Injury	44	100.0%	0	.0%	44	100.0%
Cur_Algnmt * Injury	44	100.0%	0	.0%	44	100.0%
Int_St * Injury	44	100.0%	0	.0%	44	100.0%

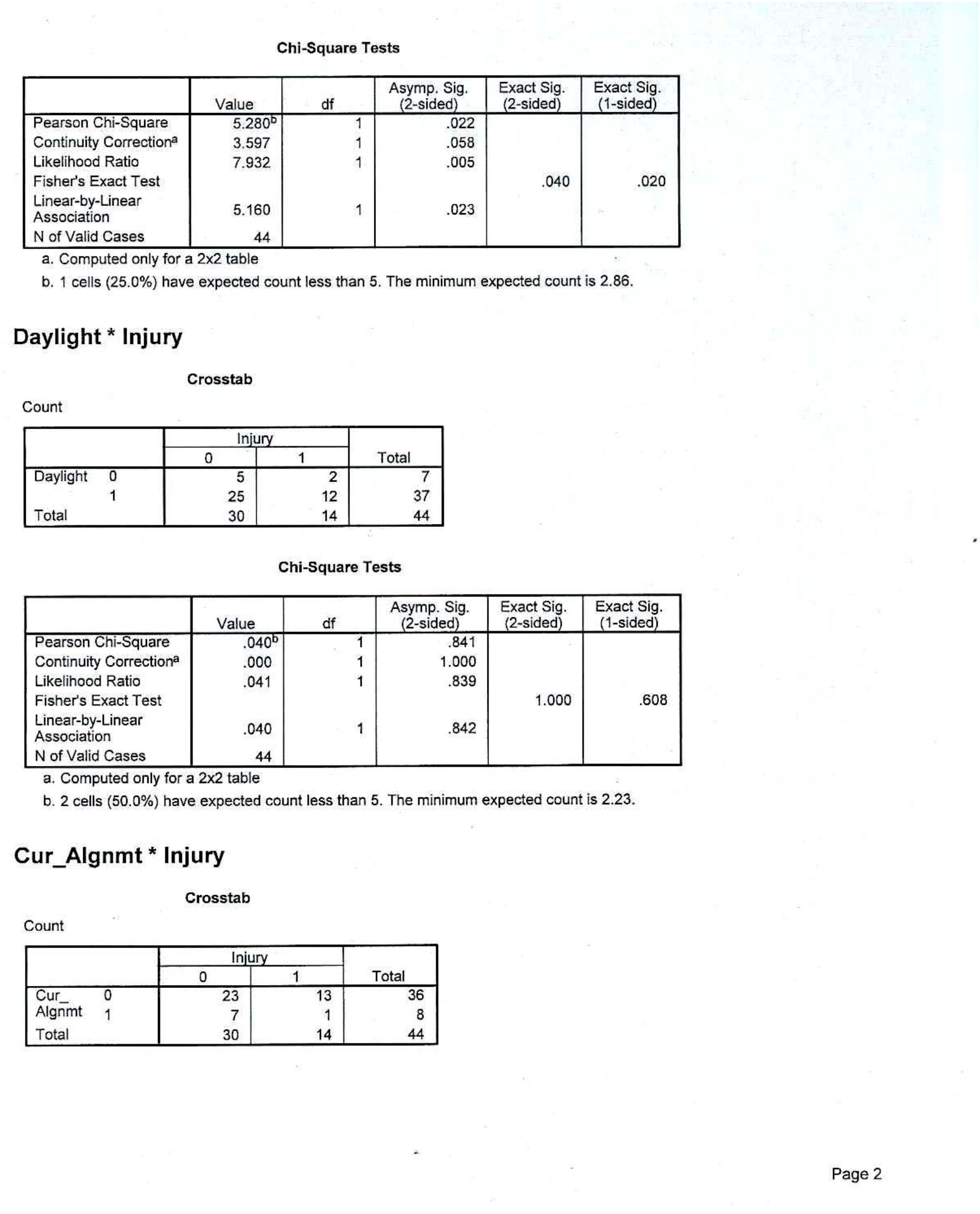
RnSnw_Wther * Injury

Crosstab

Count

		Injury		Total
		0	1	
RnSnw_Wther	0	21	14	35
	1	9	0	9
Total		30	14	44

Page 1



Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	5.280[b]	1	.022		
Continuity Correction[a]	3.597	1	.058		
Likelihood Ratio	7.932	1	.005		
Fisher's Exact Test				.040	.020
Linear-by-Linear Association	5.160	1	.023		
N of Valid Cases	44				

a. Computed only for a 2x2 table

b. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 2.86.

Daylight * Injury

Crosstab

Count

		Injury		Total
		0	1	
Daylight	0	5	2	7
	1	25	12	37
Total		30	14	44

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.040[b]	1	.841		
Continuity Correction[a]	.000	1	1.000		
Likelihood Ratio	.041	1	.839		
Fisher's Exact Test				1.000	.608
Linear-by-Linear Association	.040	1	.842		
N of Valid Cases	44				

a. Computed only for a 2x2 table

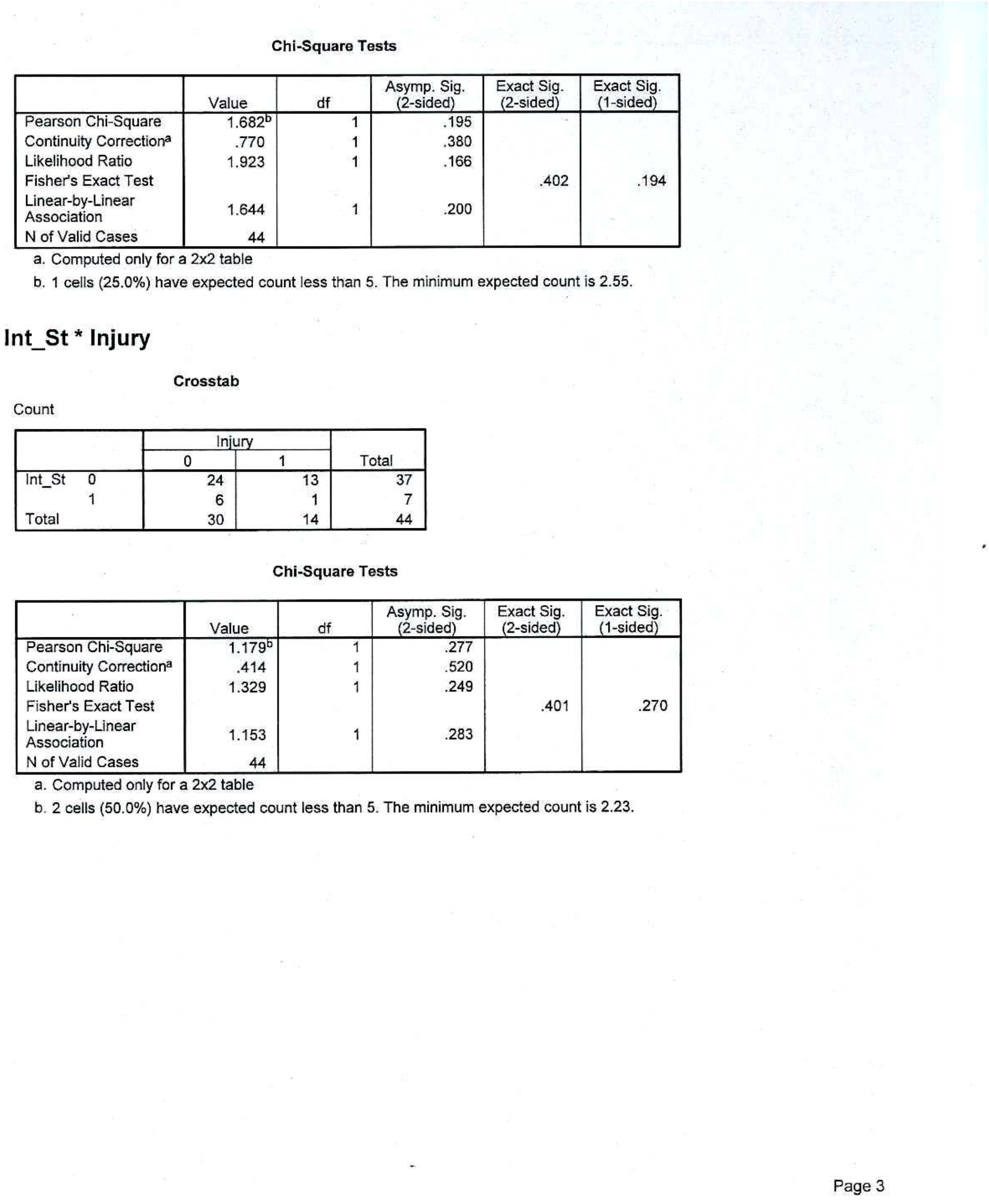
b. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 2.23.

Cur_Algnmt * Injury

Crosstab

Count

		Injury		Total
		0	1	
Cur_ Algnmt	0	23	13	36
	1	7	1	8
Total		30	14	44



Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.682[b]	1	.195		
Continuity Correction[a]	.770	1	.380		
Likelihood Ratio	1.923	1	.166		
Fisher's Exact Test				.402	.194
Linear-by-Linear Association	1.644	1	.200		
N of Valid Cases	44				

a. Computed only for a 2x2 table

b. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 2.55.

Int_St * Injury

Crosstab

Count

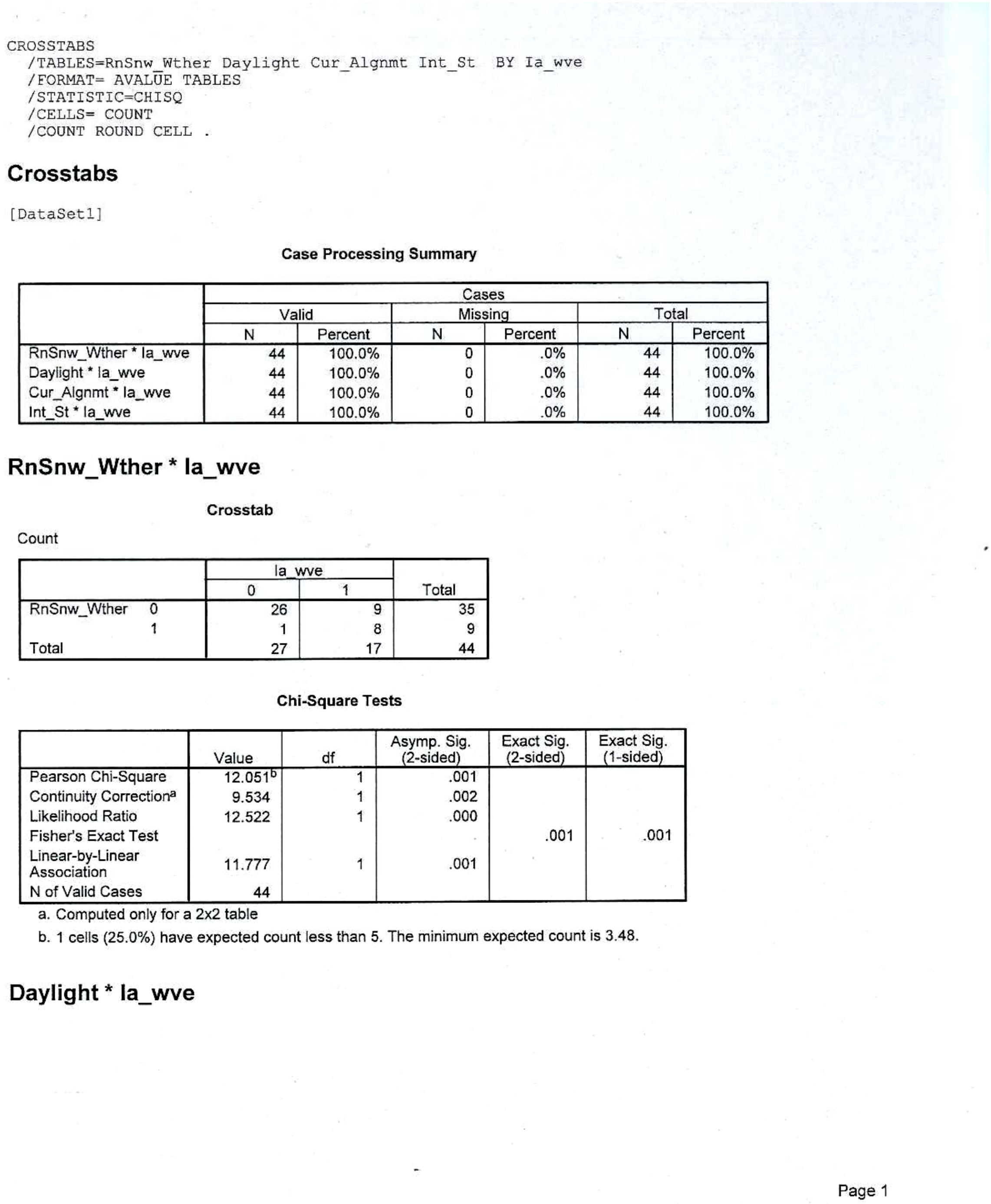
		Injury		Total
		0	1	
Int_St	0	24	13	37
	1	6	1	7
Total		30	14	44

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.179[b]	1	.277		
Continuity Correction[a]	.414	1	.520		
Likelihood Ratio	1.329	1	.249		
Fisher's Exact Test				.401	.270
Linear-by-Linear Association	1.153	1	.283		
N of Valid Cases	44				

a. Computed only for a 2x2 table

b. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 2.23.



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  /FORMAT= AVALUE TABLES
  /STATISTIC=CHISQ
  /CELLS= COUNT
  /COUNT ROUND CELL .
```

Crosstabs

`[DataSet1]`

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
RnSnw_Wther * la_wve	44	100.0%	0	.0%	44	100.0%
Daylight * la_wve	44	100.0%	0	.0%	44	100.0%
Cur_Algnmt * la_wve	44	100.0%	0	.0%	44	100.0%
Int_St * la_wve	44	100.0%	0	.0%	44	100.0%

RnSnw_Wther * la_wve

Crosstab

Count

		la_wve		Total
		0	1	
RnSnw_Wther	0	26	9	35
	1	1	8	9
Total		27	17	44

Chi-Square Tests

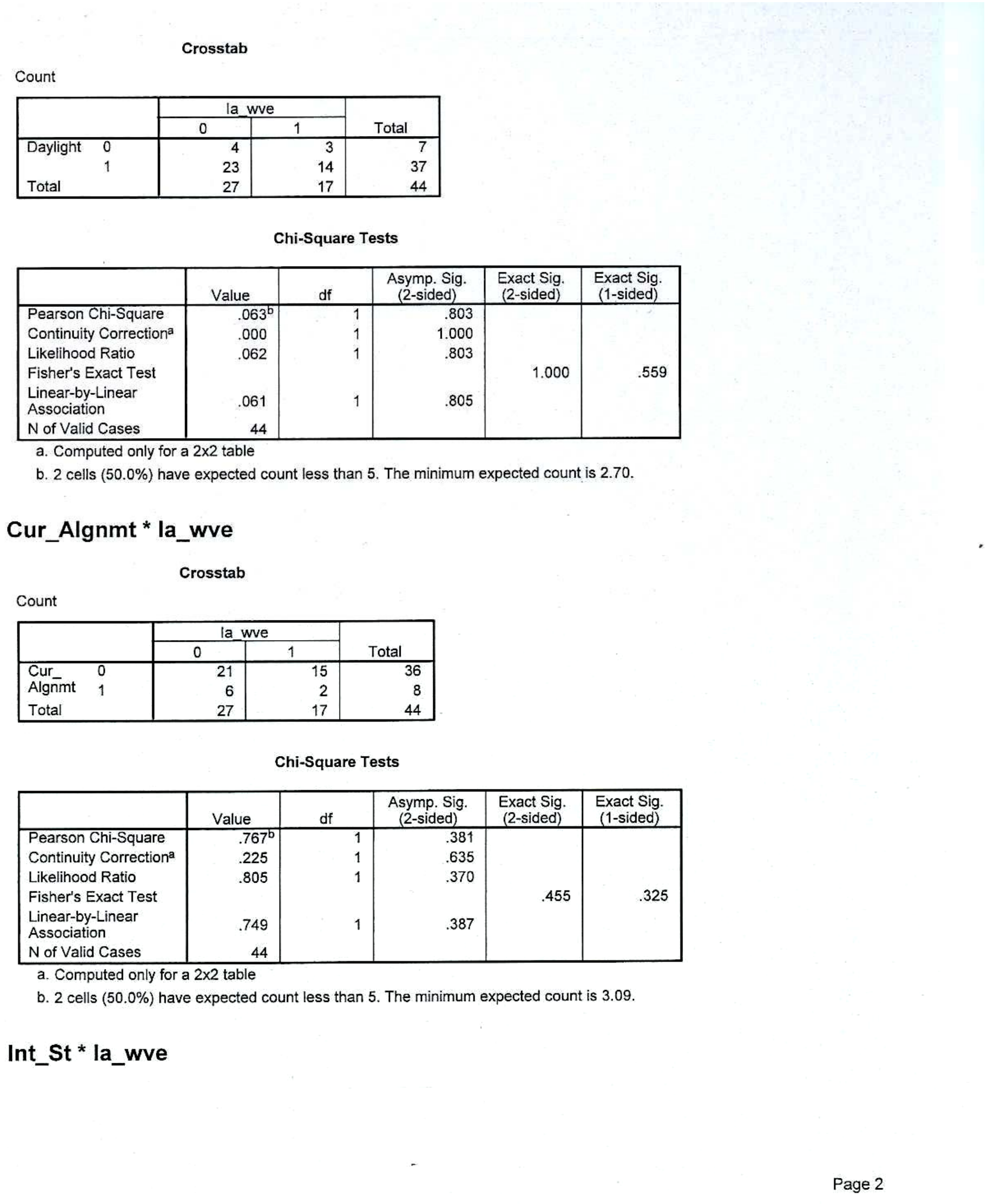
	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	12.051[b]	1	.001		
Continuity Correction[a]	9.534	1	.002		
Likelihood Ratio	12.522	1	.000		
Fisher's Exact Test				.001	.001
Linear-by-Linear Association	11.777	1	.001		
N of Valid Cases	44				

a. Computed only for a 2x2 table

b. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 3.48.

Daylight * la_wve

Page 1



Crosstab

Count

		la_wve		Total
		0	1	
Daylight	0	4	3	7
	1	23	14	37
Total		27	17	44

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.063[b]	1	.803		
Continuity Correction[a]	.000	1	1.000		
Likelihood Ratio	.062	1	.803		
Fisher's Exact Test				1.000	.559
Linear-by-Linear Association	.061	1	.805		
N of Valid Cases	44				

a. Computed only for a 2x2 table

b. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 2.70.

Cur_Algnmt * la_wve

Crosstab

Count

		la_wve		Total
		0	1	
Cur_ Algnmt	0	21	15	36
	1	6	2	8
Total		27	17	44

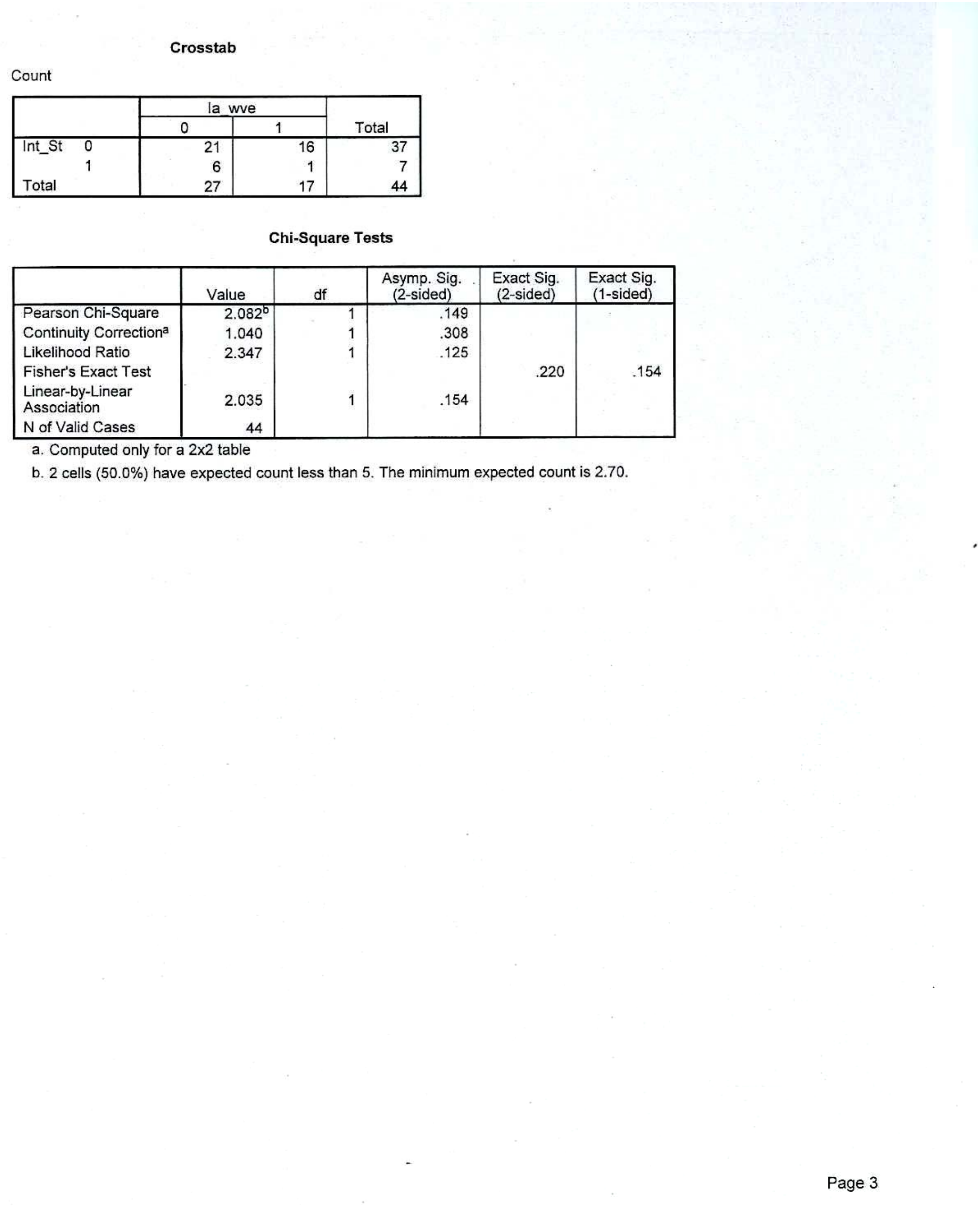
Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.767[b]	1	.381		
Continuity Correction[a]	.225	1	.635		
Likelihood Ratio	.805	1	.370		
Fisher's Exact Test				.455	.325
Linear-by-Linear Association	.749	1	.387		
N of Valid Cases	44				

a. Computed only for a 2x2 table

b. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 3.09.

Int_St * la_wve



Crosstab

Count

		la_wve		
		0	1	Total
Int_St	0	21	16	37
	1	6	1	7
Total		27	17	44

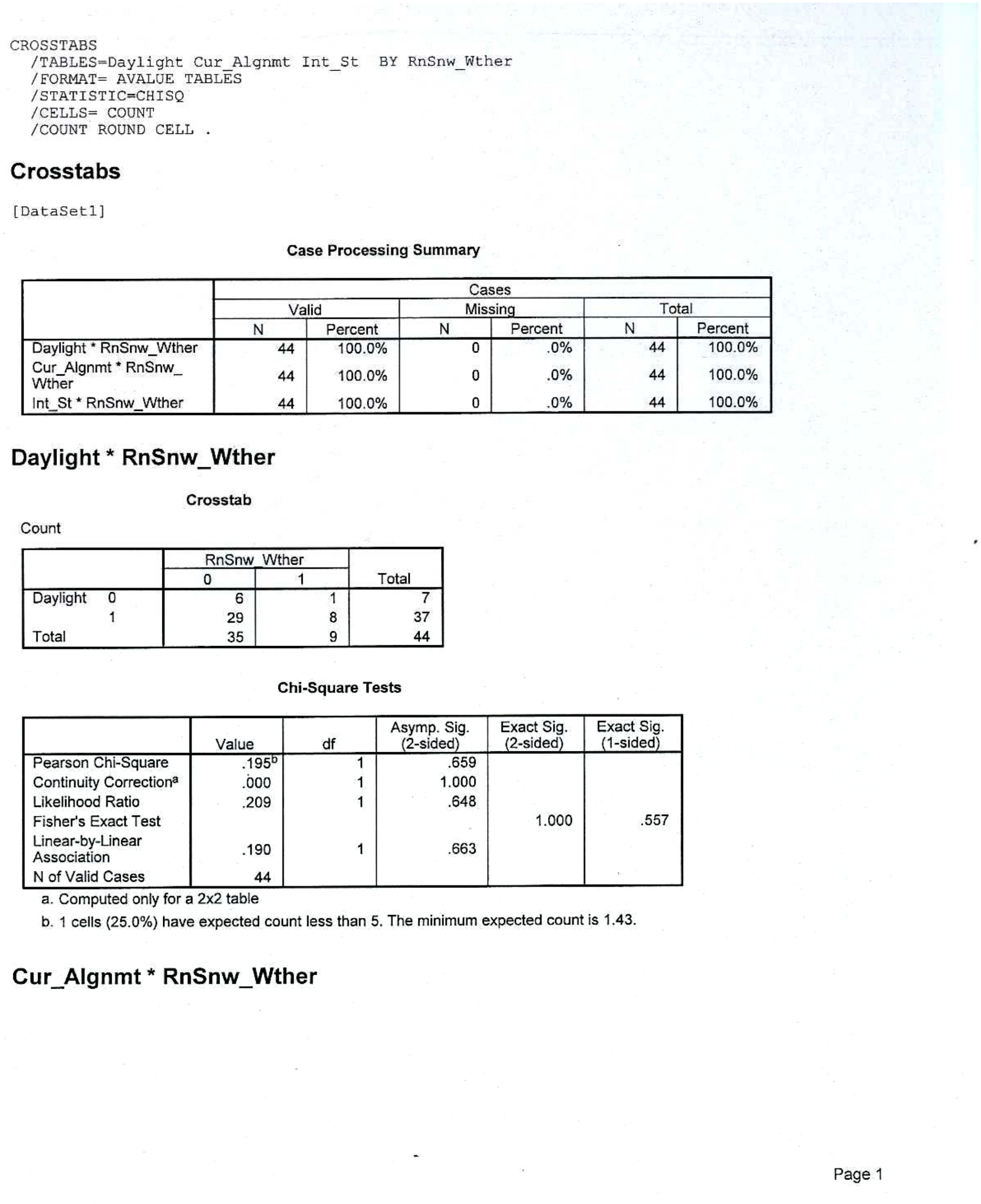
Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.082[b]	1	.149		
Continuity Correction[a]	1.040	1	.308		
Likelihood Ratio	2.347	1	.125		
Fisher's Exact Test				.220	.154
Linear-by-Linear Association	2.035	1	.154		
N of Valid Cases	44				

a. Computed only for a 2x2 table

b. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 2.70.

Page 3



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  /CELLS= COUNT
  /COUNT ROUND CELL .
```

Crosstabs

```
[DataSet1]
```

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Daylight * RnSnw_Wther	44	100.0%	0	.0%	44	100.0%
Cur_Algnmt * RnSnw_ Wther	44	100.0%	0	.0%	44	100.0%
Int_St * RnSnw_Wther	44	100.0%	0	.0%	44	100.0%

Daylight * RnSnw_Wther

Crosstab

Count

		RnSnw_Wther		Total
		0	1	
Daylight	0	6	1	7
	1	29	8	37
Total		35	9	44

Chi-Square Tests

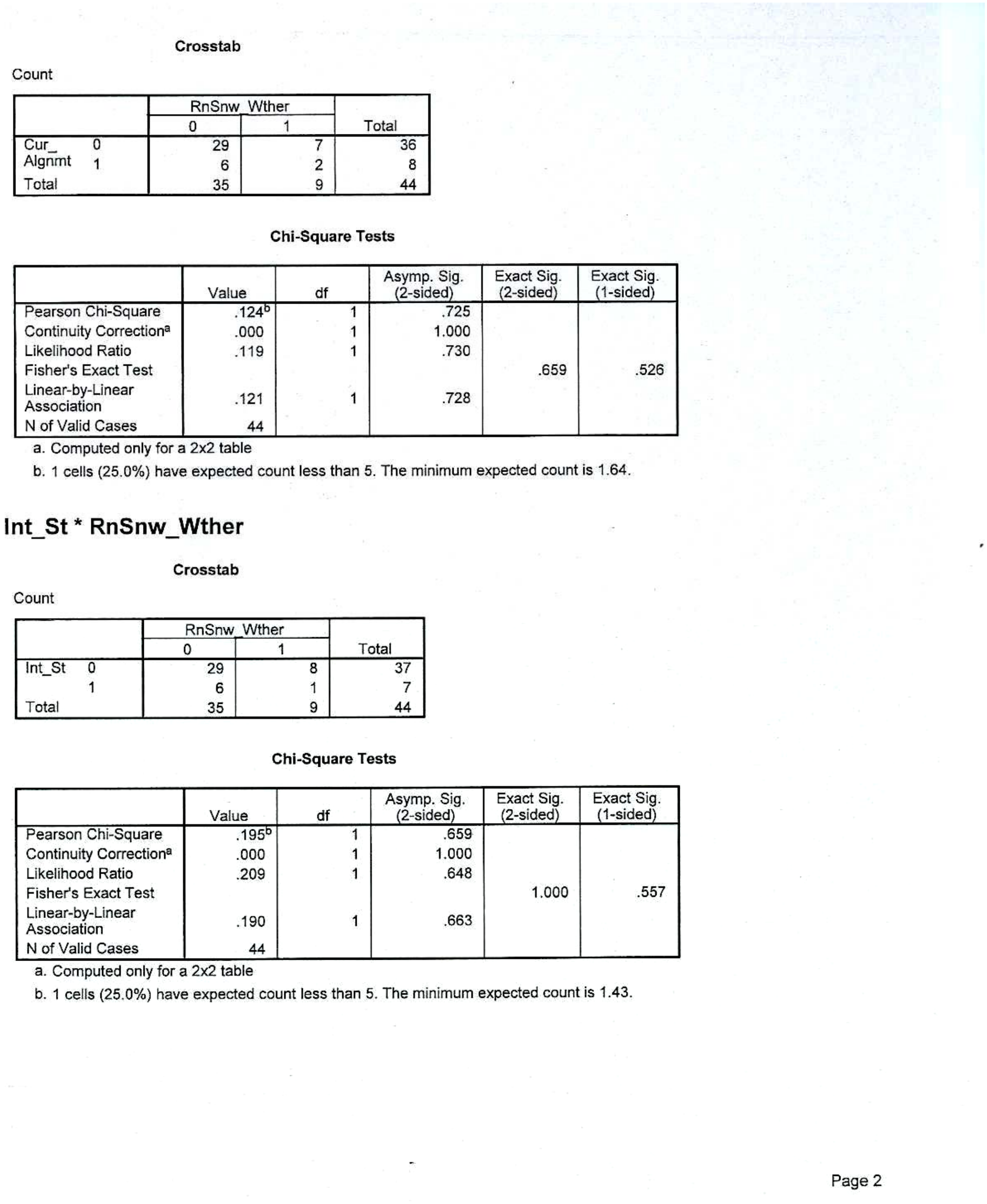
	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.195[b]	1	.659		
Continuity Correction[a]	.000	1	1.000		
Likelihood Ratio	.209	1	.648		
Fisher's Exact Test				1.000	.557
Linear-by-Linear Association	.190	1	.663		
N of Valid Cases	44				

a. Computed only for a 2x2 table

b. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 1.43.

Cur_Algnmt * RnSnw_Wther

Page 1



Crosstab

Count

		RnSnw_Wther		
		0	1	Total
Cur_ Algnmt	0	29	7	36
	1	6	2	8
Total		35	9	44

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.124[b]	1	.725		
Continuity Correction[a]	.000	1	1.000		
Likelihood Ratio	.119	1	.730		
Fisher's Exact Test				.659	.526
Linear-by-Linear Association	.121	1	.728		
N of Valid Cases	44				

a. Computed only for a 2x2 table

b. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 1.64.

Int_St * RnSnw_Wther

Crosstab

Count

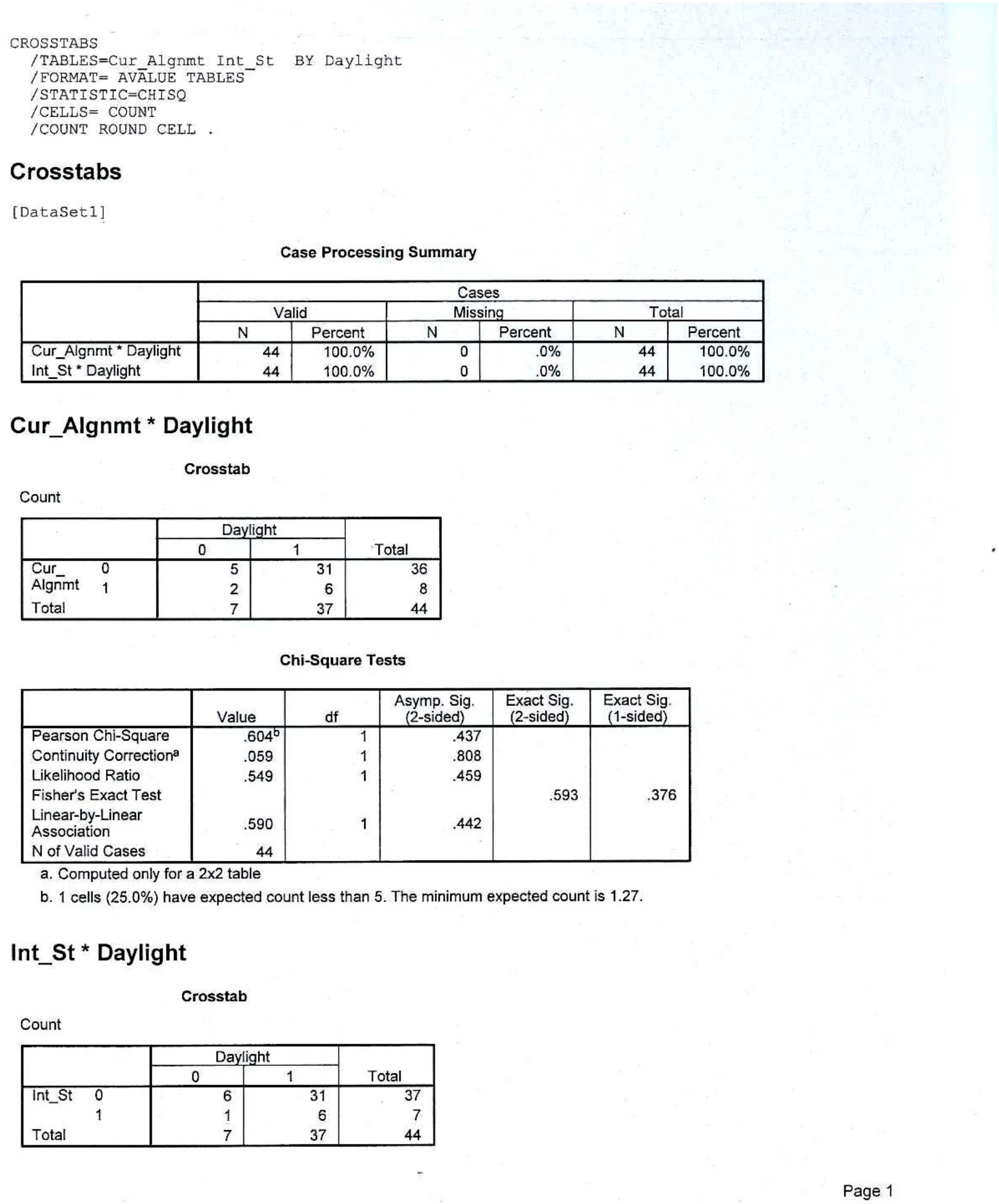
		RnSnw_Wther		
		0	1	Total
Int_St	0	29	8	37
	1	6	1	7
Total		35	9	44

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.195[b]	1	.659		
Continuity Correction[a]	.000	1	1.000		
Likelihood Ratio	.209	1	.648		
Fisher's Exact Test				1.000	.557
Linear-by-Linear Association	.190	1	.663		
N of Valid Cases	44				

a. Computed only for a 2x2 table

b. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 1.43.



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  /CELLS= COUNT
  /COUNT ROUND CELL .
```

Crosstabs

```
[DataSet1]
```

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Cur_Algnmt * Daylight	44	100.0%	0	.0%	44	100.0%
Int_St * Daylight	44	100.0%	0	.0%	44	100.0%

Cur_Algnmt * Daylight

Crosstab

Count

		Daylight		Total
		0	1	
Cur_ Algnmt	0	5	31	36
	1	2	6	8
Total		7	37	44

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.604[b]	1	.437		
Continuity Correction[a]	.059	1	.808		
Likelihood Ratio	.549	1	.459		
Fisher's Exact Test				.593	.376
Linear-by-Linear Association	.590	1	.442		
N of Valid Cases	44				

a. Computed only for a 2x2 table

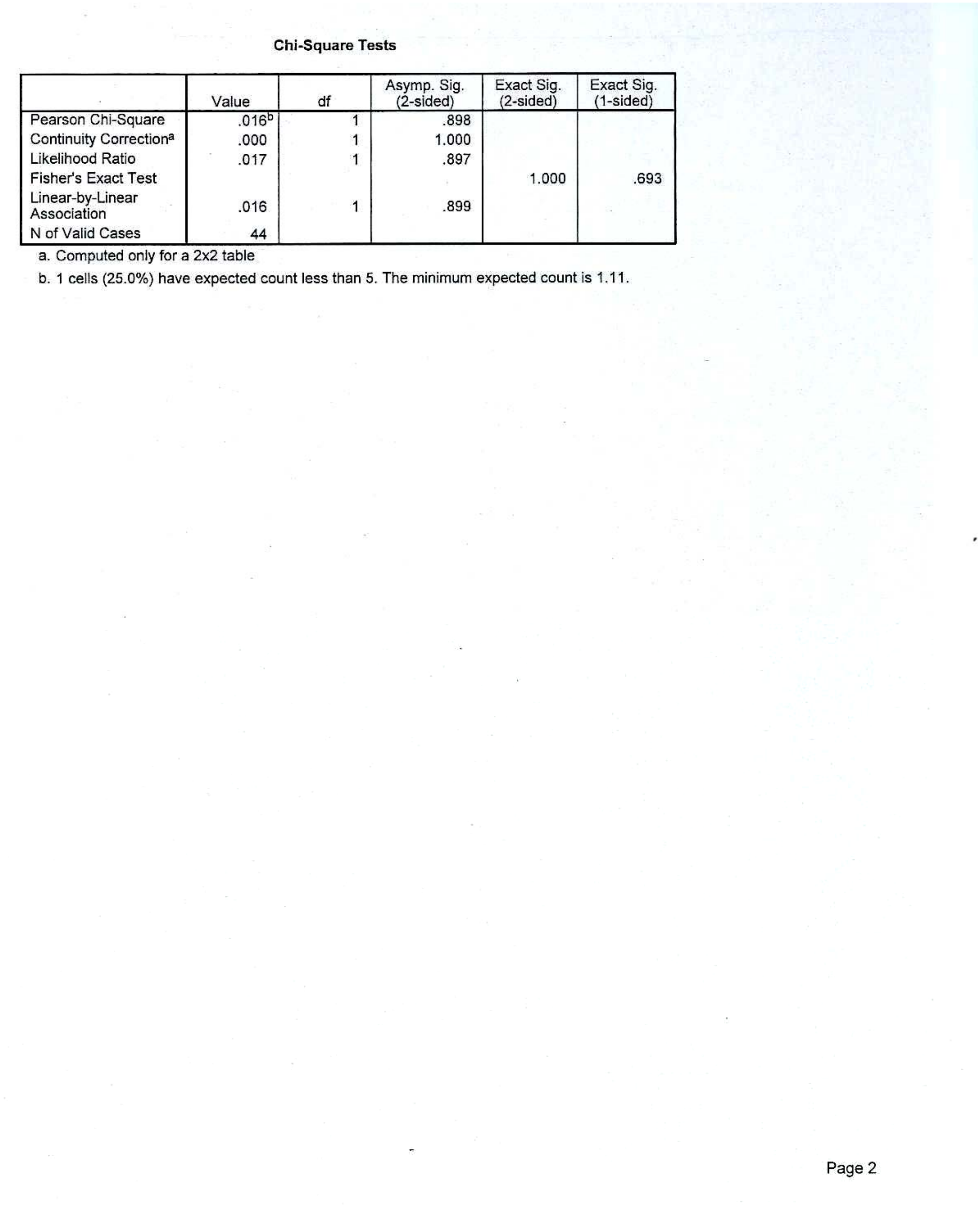
b. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 1.27.

Int_St * Daylight

Crosstab

Count

		Daylight		Total
		0	1	
Int_St	0	6	31	37
	1	1	6	7
Total		7	37	44

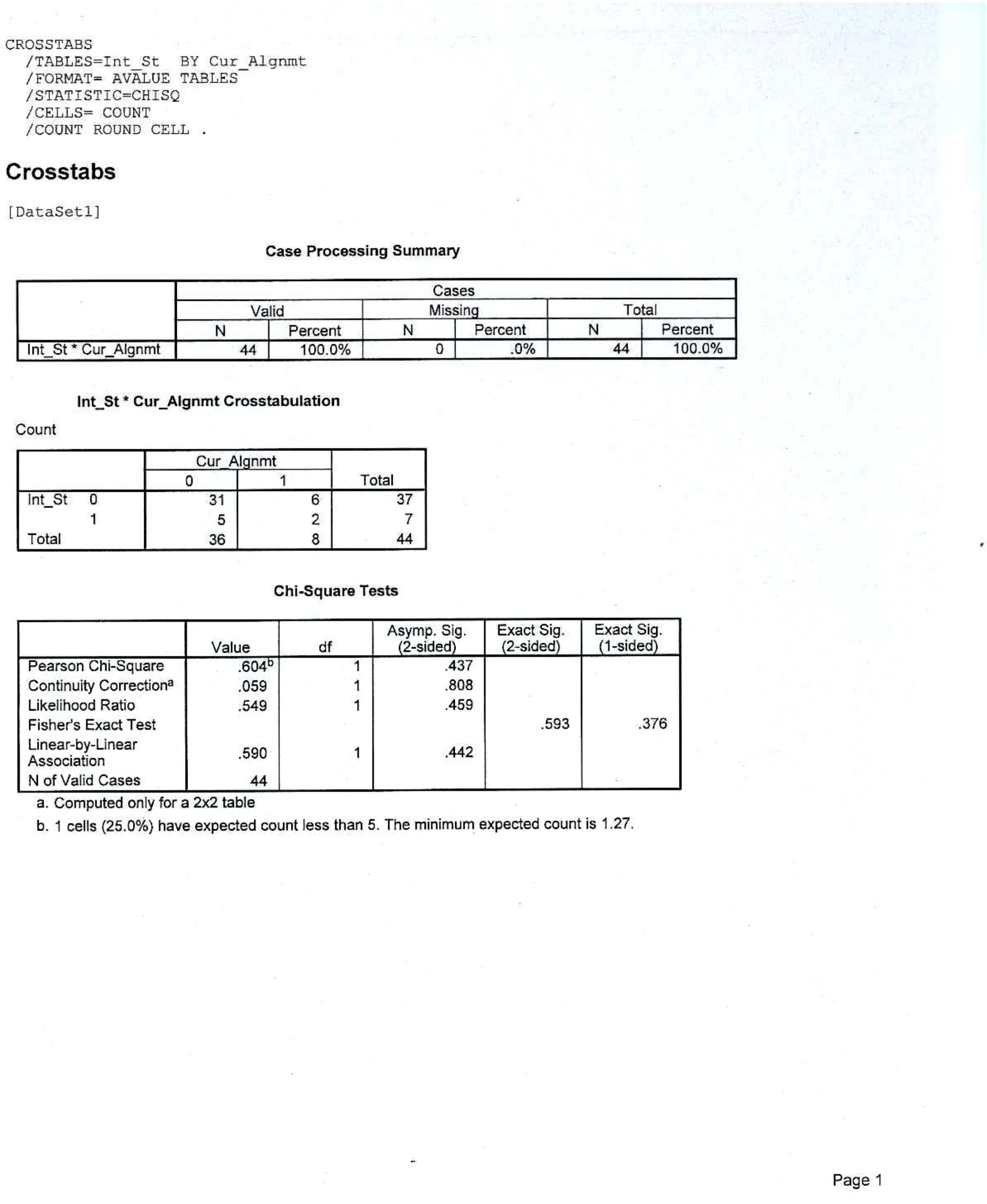


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.016[b]	1	.898		
Continuity Correction[a]	.000	1	1.000		
Likelihood Ratio	.017	1	.897		
Fisher's Exact Test				1.000	.693
Linear-by-Linear Association	.016	1	.899		
N of Valid Cases	44				

a. Computed only for a 2x2 table

b. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 1.11.



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  /STATISTIC=CHISQ
  /CELLS= COUNT
  /COUNT ROUND CELL .
```

Crosstabs

```
[DataSet1]
```

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Int_St * Cur_Algnmt	44	100.0%	0	.0%	44	100.0%

Int_St * Cur_Algnmt Crosstabulation

Count

		Cur_Algnmt		
		0	1	Total
Int_St	0	31	6	37
	1	5	2	7
Total		36	8	44

Chi-Square Tests

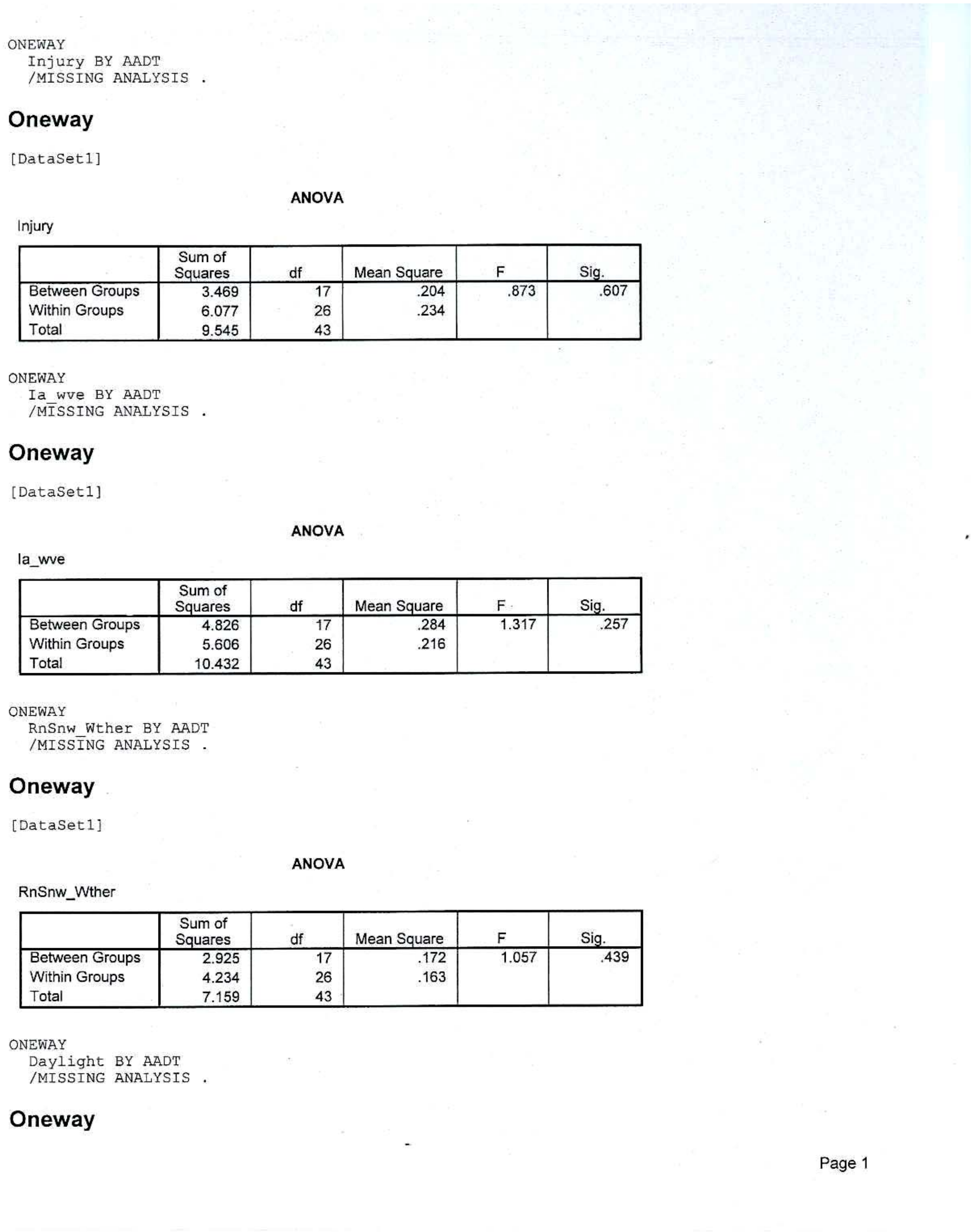
	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.604[b]	1	.437		
Continuity Correction[a]	.059	1	.808		
Likelihood Ratio	.549	1	.459		
Fisher's Exact Test				.593	.376
Linear-by-Linear Association	.590	1	.442		
N of Valid Cases	44				

a. Computed only for a 2x2 table

b. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 1.27.

Page 1

Appendix C: One-Way ANOVA Test



```
ONEWAY
  Injury BY AADT
  /MISSING ANALYSIS .
```

Oneway

```
[DataSet1]
```

ANOVA

Injury

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3.469	17	.204	.873	.607
Within Groups	6.077	26	.234		
Total	9.545	43			

```
ONEWAY
  Ia_wve BY AADT
  /MISSING ANALYSIS .
```

Oneway

```
[DataSet1]
```

ANOVA

Ia_wve

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.826	17	.284	1.317	.257
Within Groups	5.606	26	.216		
Total	10.432	43			

```
ONEWAY
  RnSnw_Wther BY AADT
  /MISSING ANALYSIS .
```

Oneway

```
[DataSet1]
```

ANOVA

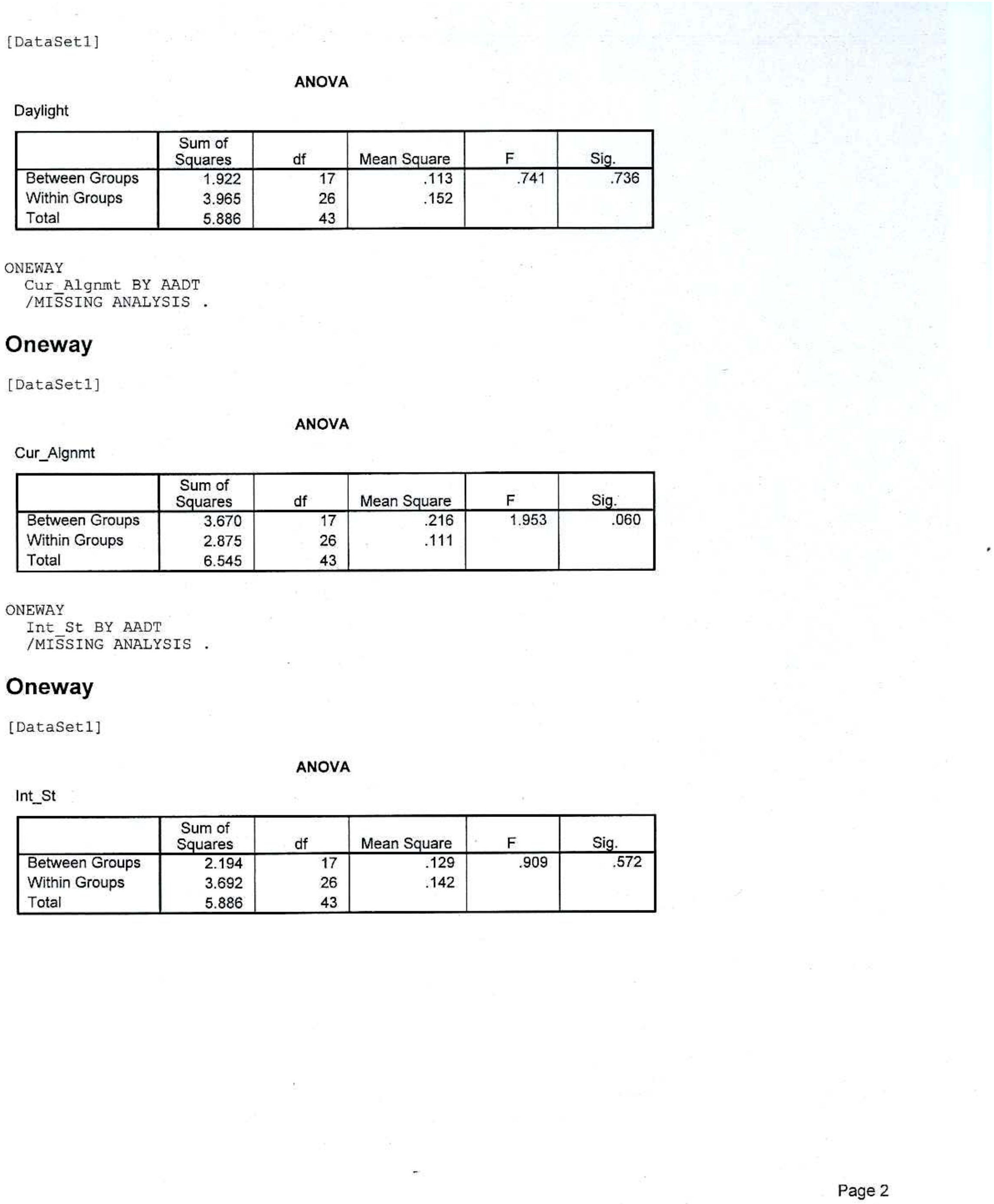
RnSnw_Wther

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.925	17	.172	1.057	.439
Within Groups	4.234	26	.163		
Total	7.159	43			

```
ONEWAY
  Daylight BY AADT
  /MISSING ANALYSIS .
```

Oneway

Page 1



```
[DataSet1]
```

ANOVA

Daylight

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.922	17	.113	.741	.736
Within Groups	3.965	26	.152		
Total	5.886	43			

```
ONEWAY
  Cur_Alignmt BY AADT
  /MISSING ANALYSIS .
```

Oneway

```
[DataSet1]
```

ANOVA

Cur_Alignmt

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3.670	17	.216	1.953	.060
Within Groups	2.875	26	.111		
Total	6.545	43			

```
ONEWAY
  Int_St BY AADT
  /MISSING ANALYSIS .
```

Oneway

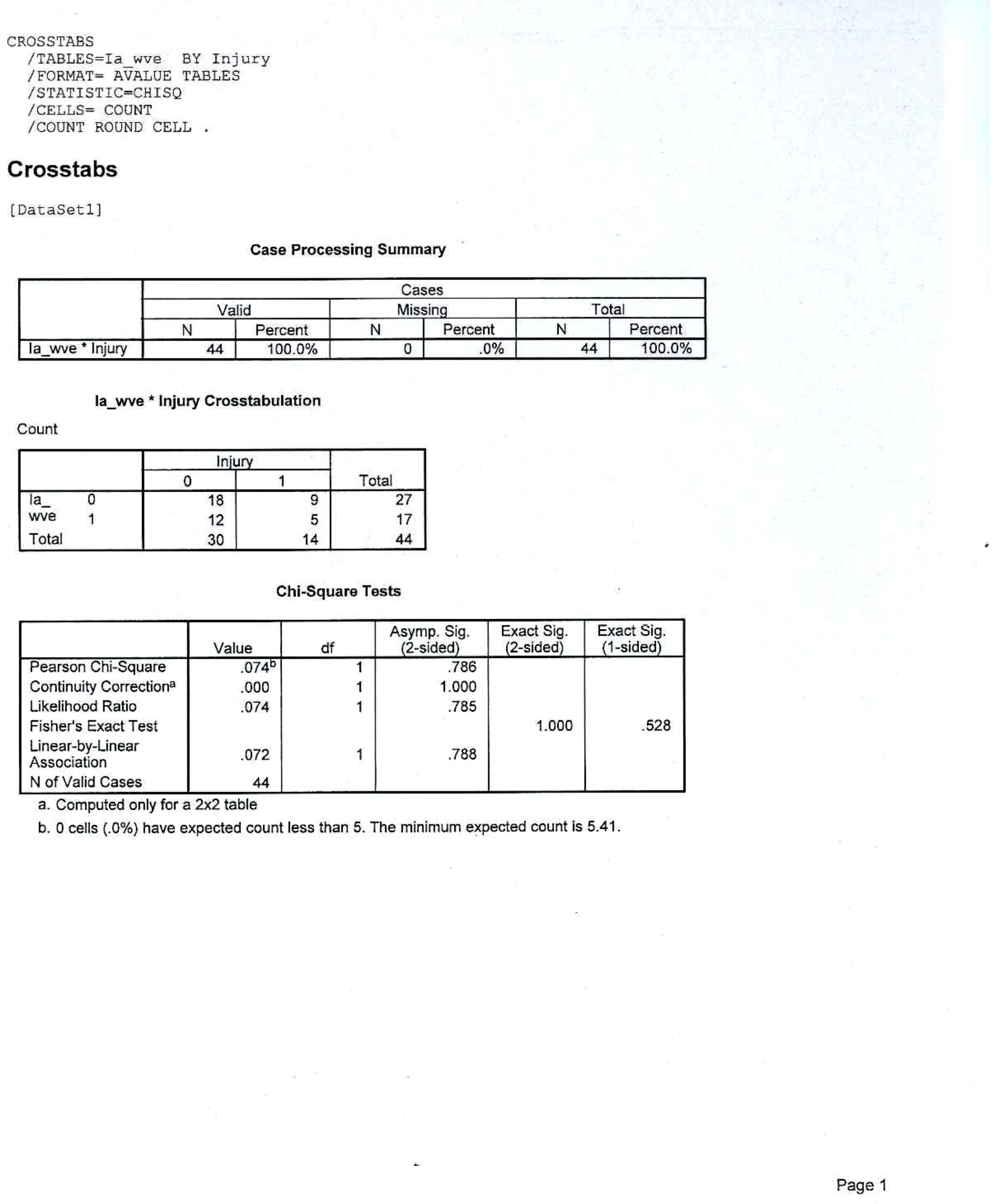
```
[DataSet1]
```

ANOVA

Int_St

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.194	17	.129	.909	.572
Within Groups	3.692	26	.142		
Total	5.886	43			

Appendix D: Goodness-of-Fit Test (Pearson Chi-Square)



```
CROSSTABS
  /TABLES=Ia_wve  BY Injury
  /FORMAT= AVALUE TABLES
  /STATISTIC=CHISQ
  /CELLS= COUNT
  /COUNT ROUND CELL .
```

Crosstabs

[DataSet1]

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Ia_wve * Injury	44	100.0%	0	.0%	44	100.0%

Ia_wve * Injury Crosstabulation

Count

		Injury		Total
		0	1	
Ia_ wve	0	18	9	27
	1	12	5	17
Total		30	14	44

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.074[b]	1	.786		
Continuity Correction[a]	.000	1	1.000		
Likelihood Ratio	.074	1	.785		
Fisher's Exact Test				1.000	.528
Linear-by-Linear Association	.072	1	.788		
N of Valid Cases	44				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.41.

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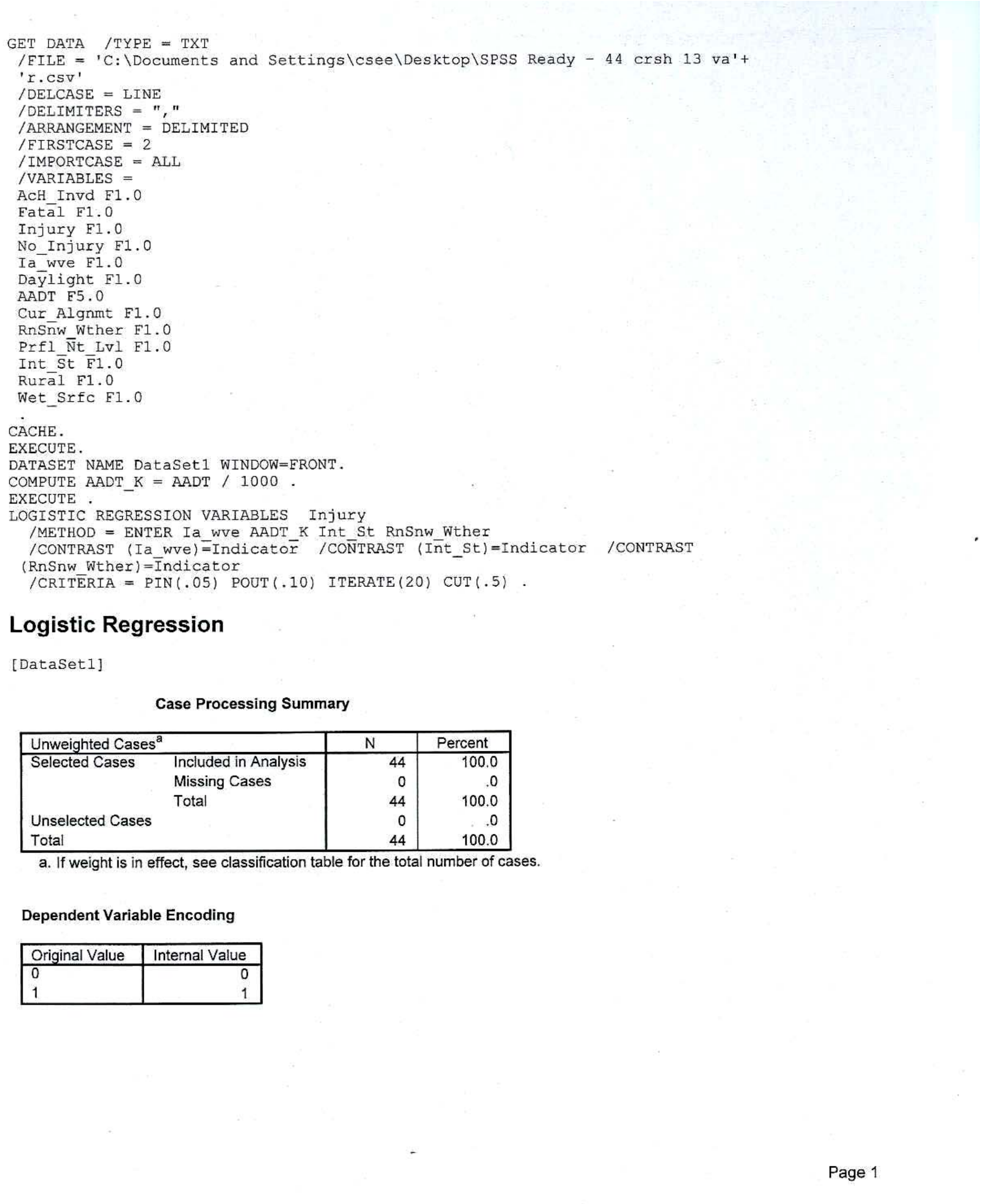
Appendix E: Paired t-Test

Project	Conventional	Iowa Weave
B30100	0.2048	0
B10107	1.1947	0.5974
BX0102	0.2038	0.1359
B80103	0.0893	0.0893
BX0101	0.2819	0.2819
B60106	0.2471	0.2059
B80108	0.2293	0.0573
B10104	0.317	0
B40105	0.0877	0.1753
BX0100	0	0

t-Test: Paired Two Sample for Means

	Conventional	Iowa Weave
Mean	0.28556	0.1543
Variance	0.11162	0.03346
Observations	10	10
Pearson Correlation	0.85022	
Hypothesized Mean Difference	0	
df	9	
t Stat	2.04586	
P(T<=t) one-tail	0.03554	
t Critical one-tail	1.83311	

Appendix F: Logistic Regression Model – First Model



```
GET DATA  /TYPE = TXT
 /FILE = 'C:\Documents and Settings\csee\Desktop\SPSS Ready - 44 crsh 13 va'+
 'r.csv'
 /DELCASE = LINE
 /DELIMITERS = ","
 /ARRANGEMENT = DELIMITED
 /FIRSTCASE = 2
 /IMPORTCASE = ALL
 /VARIABLES =
 AcH_Invd F1.0
 Fatal F1.0
 Injury F1.0
 No_Injury F1.0
 Ia_wve F1.0
 Daylight F1.0
 AADT F5.0
 Cur_Algnmt F1.0
 RnSnw_Wther F1.0
 Prfl_Nt_Lvl F1.0
 Int_St F1.0
 Rural F1.0
 Wet_Srfc F1.0
 .
CACHE.
EXECUTE.
DATASET NAME DataSet1 WINDOW=FRONT.
COMPUTE AADT_K = AADT / 1000 .
EXECUTE .
LOGISTIC REGRESSION VARIABLES  Injury
  /METHOD = ENTER Ia_wve AADT_K Int_St RnSnw_Wther
  /CONTRAST (Ia_wve)=Indicator  /CONTRAST (Int_St)=Indicator  /CONTRAST
 (RnSnw_Wther)=Indicator
  /CRITERIA = PIN(.05) POUT(.10) ITERATE(20) CUT(.5) .
```

Logistic Regression

```
[DataSet1]
```

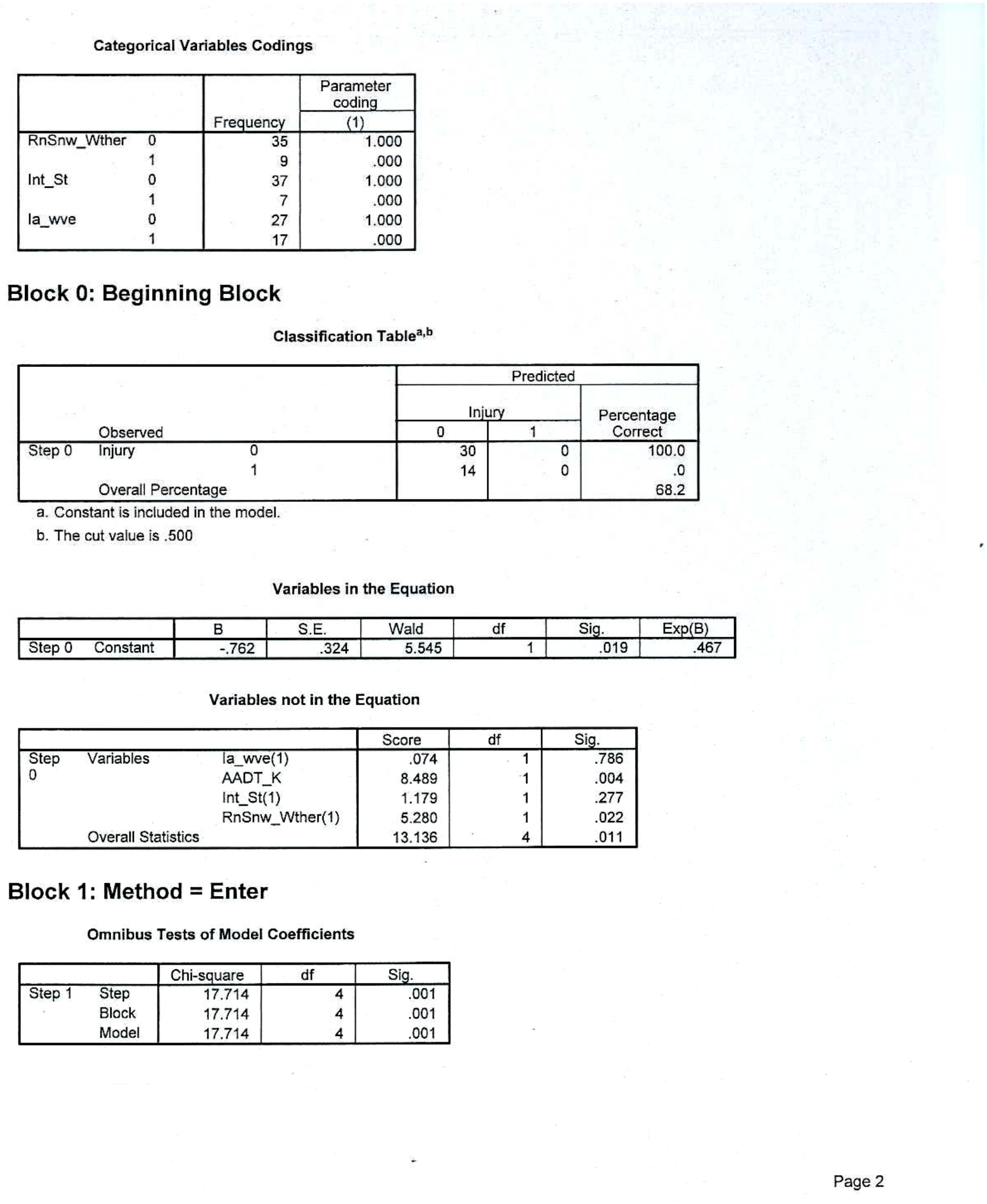
Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	44	100.0
	Missing Cases	0	.0
	Total	44	100.0
Unselected Cases		0	.0
Total		44	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
0	0
1	1



Categorical Variables Codings

		Frequency	Parameter coding (1)
RnSnw_Wther	0	35	1.000
	1	9	.000
Int_St	0	37	1.000
	1	7	.000
la_wve	0	27	1.000
	1	17	.000

Block 0: Beginning Block

Classification Table[a,b]

	Observed		Predicted: Injury 0	Predicted: Injury 1	Predicted: Percentage Correct
Step 0	Injury	0	30	0	100.0
		1	14	0	.0
	Overall Percentage				68.2

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	-.762	.324	5.545	1	.019	.467

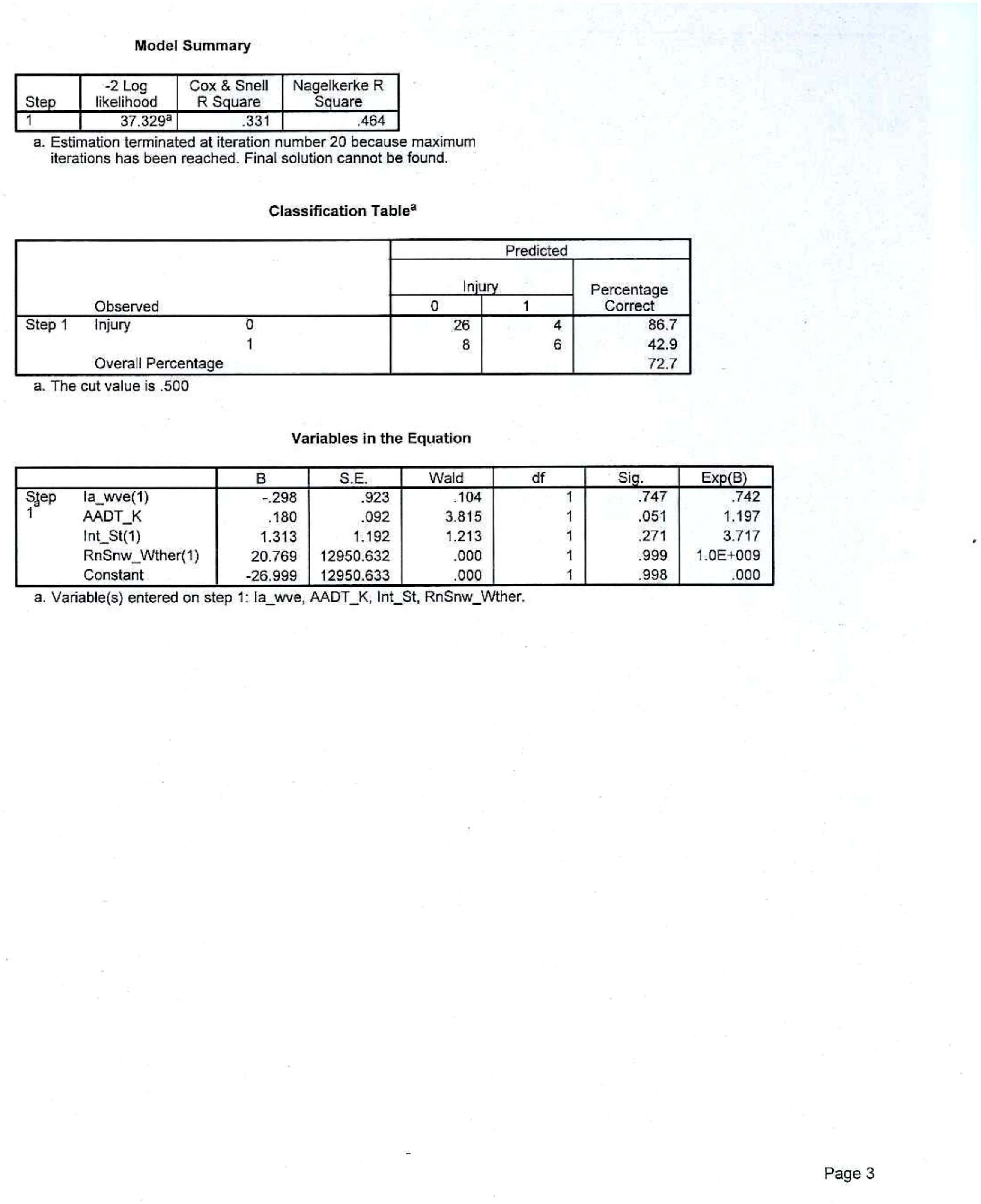
Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	la_wve(1)	.074	1	.786
		AADT_K	8.489	1	.004
		Int_St(1)	1.179	1	.277
		RnSnw_Wther(1)	5.280	1	.022
	Overall Statistics		13.136	4	.011

Block 1: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	17.714	4	.001
	Block	17.714	4	.001
	Model	17.714	4	.001



Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	37.329[a]	.331	.464

a. Estimation terminated at iteration number 20 because maximum iterations has been reached. Final solution cannot be found.

Classification Table[a]

			Predicted		
			Injury		Percentage Correct
	Observed		0	1	
Step 1	Injury	0	26	4	86.7
		1	8	6	42.9
	Overall Percentage				72.7

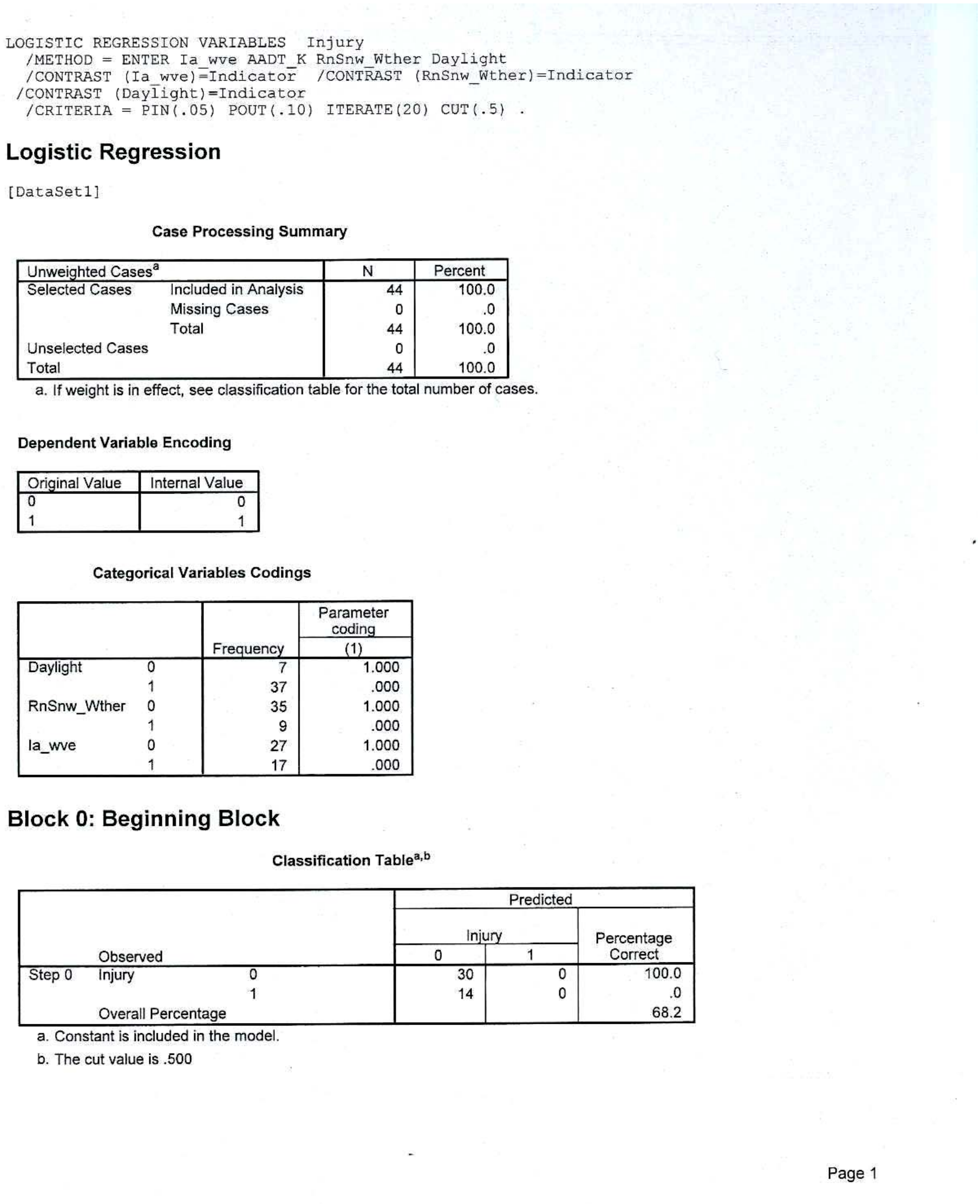
a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Ia_wve(1)	-.298	.923	.104	1	.747	.742
	AADT_K	.180	.092	3.815	1	.051	1.197
	Int_St(1)	1.313	1.192	1.213	1	.271	3.717
	RnSnw_Wther(1)	20.769	12950.632	.000	1	.999	1.0E+009
	Constant	-26.999	12950.633	.000	1	.998	.000

a. Variable(s) entered on step 1: Ia_wve, AADT_K, Int_St, RnSnw_Wther.

Appendix G: Logistic Regression Model – Second Model



```
LOGISTIC REGRESSION VARIABLES  Injury
  /METHOD = ENTER Ia_wve AADT_K RnSnw_Wther Daylight
  /CONTRAST (Ia_wve)=Indicator  /CONTRAST (RnSnw_Wther)=Indicator
 /CONTRAST (Daylight)=Indicator
  /CRITERIA = PIN(.05) POUT(.10) ITERATE(20) CUT(.5) .
```

Logistic Regression

[DataSet1]

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	44	100.0
	Missing Cases	0	.0
	Total	44	100.0
Unselected Cases		0	.0
Total		44	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
0	0
1	1

Categorical Variables Codings

		Frequency	Parameter coding (1)
Daylight	0	7	1.000
	1	37	.000
RnSnw_Wther	0	35	1.000
	1	9	.000
Ia_wve	0	27	1.000
	1	17	.000

Block 0: Beginning Block

Classification Table[a,b]

	Observed		Predicted Injury 0	Predicted Injury 1	Percentage Correct
Step 0	Injury	0	30	0	100.0
		1	14	0	.0
	Overall Percentage				68.2

a. Constant is included in the model.

b. The cut value is .500

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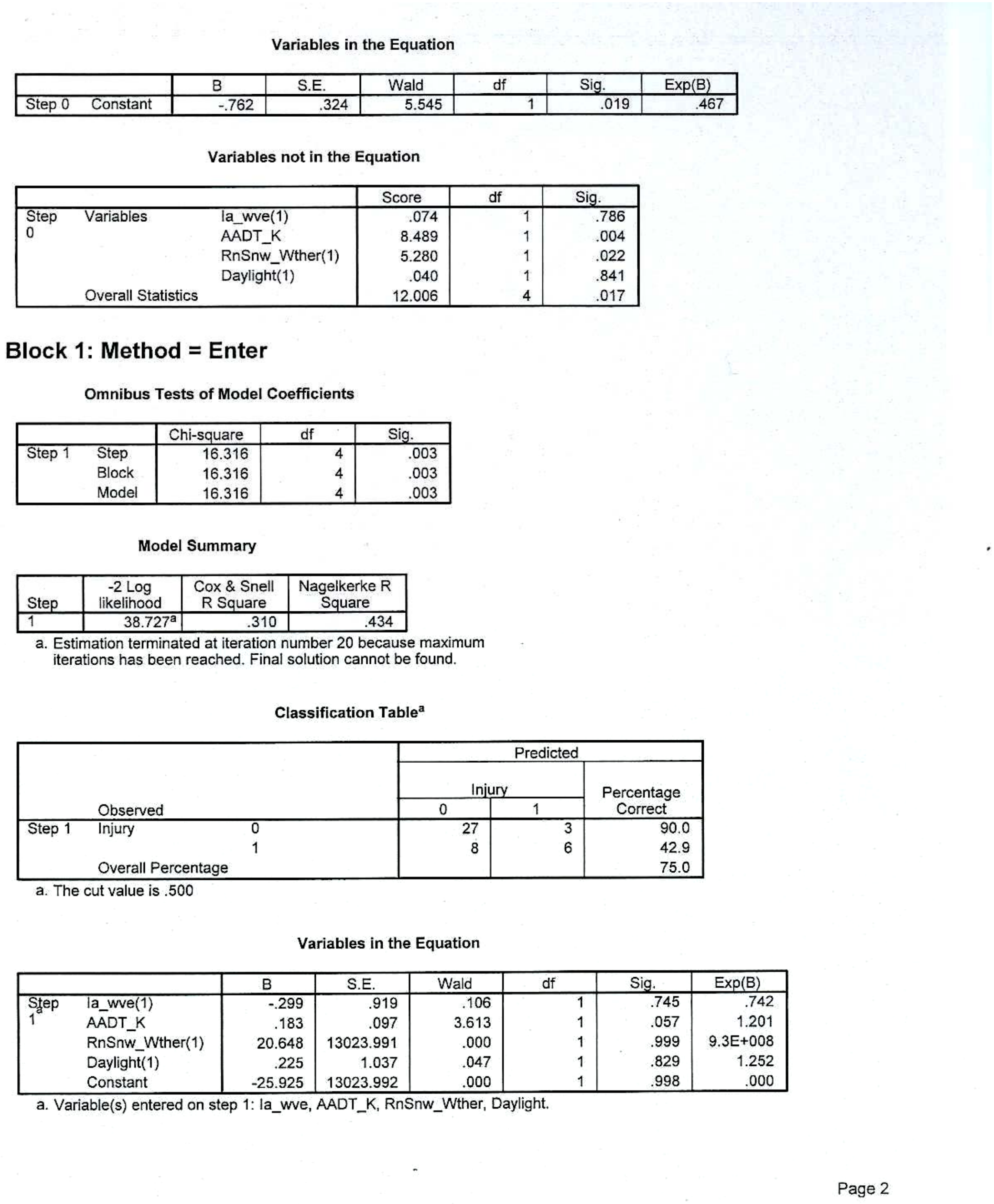

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	-.762	.324	5.545	1	.019	.467

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	la_wve(1)	.074	1	.786
		AADT_K	8.489	1	.004
		RnSnw_Wther(1)	5.280	1	.022
		Daylight(1)	.040	1	.841
	Overall Statistics		12.006	4	.017

Block 1: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	16.316	4	.003
	Block	16.316	4	.003
	Model	16.316	4	.003

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	38.727[a]	.310	.434

a. Estimation terminated at iteration number 20 because maximum iterations has been reached. Final solution cannot be found.

Classification Table[a]

			Predicted		
			Injury		Percentage Correct
	Observed		0	1	
Step 1	Injury	0	27	3	90.0
		1	8	6	42.9
	Overall Percentage				75.0

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	la_wve(1)	-.299	.919	.106	1	.745	.742
	AADT_K	.183	.097	3.613	1	.057	1.201
	RnSnw_Wther(1)	20.648	13023.991	.000	1	.999	9.3E+008
	Daylight(1)	.225	1.037	.047	1	.829	1.252
	Constant	-25.925	13023.992	.000	1	.998	.000

a. Variable(s) entered on step 1: la_wve, AADT_K, RnSnw_Wther, Daylight.

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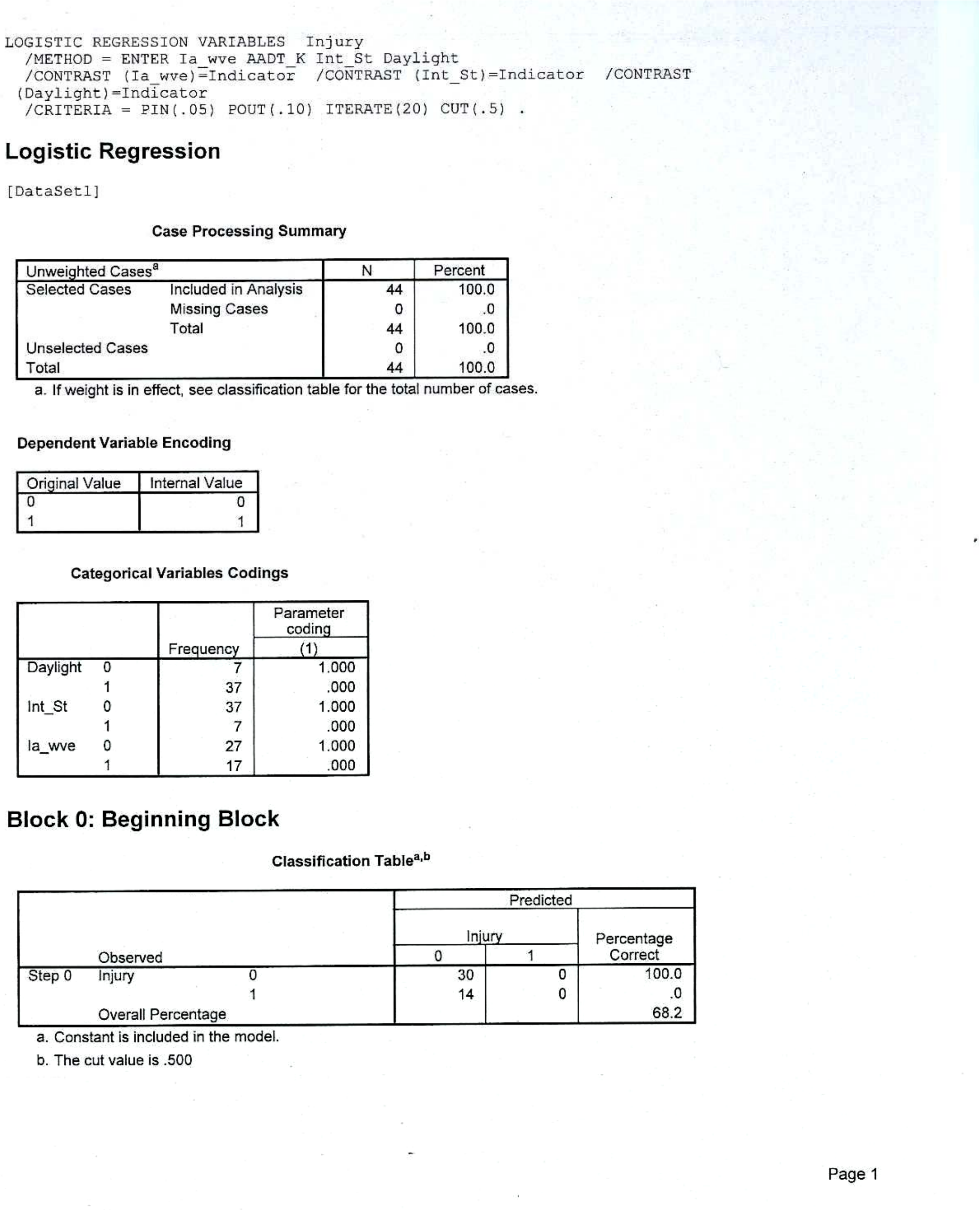
Appendix H: Logistic Regression Model – Third Model (Final)



```
LOGISTIC REGRESSION VARIABLES  Injury
  /METHOD = ENTER Ia_wve AADT_K Int_St Daylight
  /CONTRAST (Ia_wve)=Indicator  /CONTRAST (Int_St)=Indicator  /CONTRAST
 (Daylight)=Indicator
  /CRITERIA = PIN(.05) POUT(.10) ITERATE(20) CUT(.5) .
```

Logistic Regression

[DataSet1]

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	44	100.0
	Missing Cases	0	.0
	Total	44	100.0
Unselected Cases		0	.0
Total		44	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
0	0
1	1

Categorical Variables Codings

		Frequency	Parameter coding (1)
Daylight	0	7	1.000
	1	37	.000
Int_St	0	37	1.000
	1	7	.000
Ia_wve	0	27	1.000
	1	17	.000

Block 0: Beginning Block

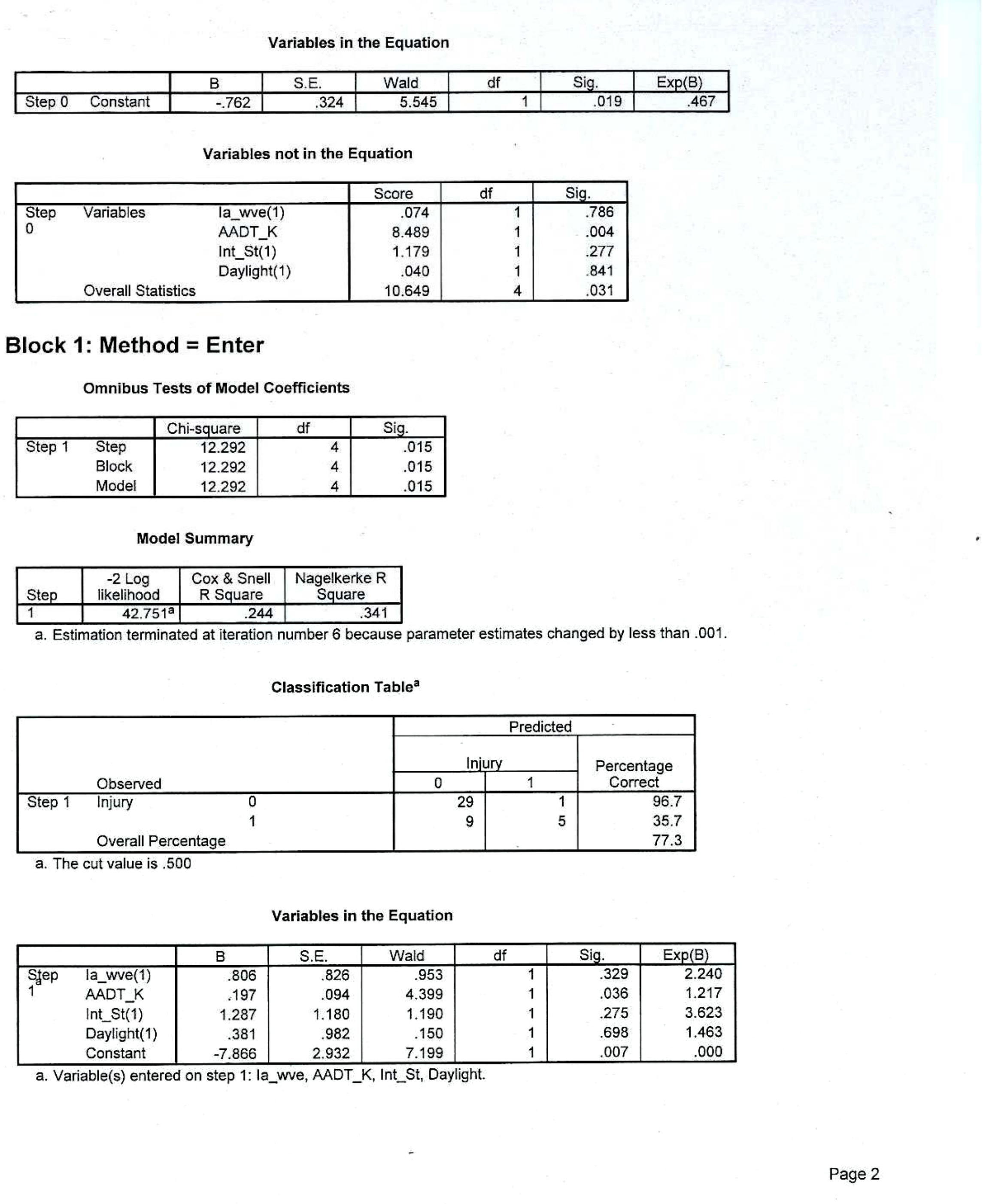
Classification Table[a,b]

			Predicted		
			Injury		Percentage Correct
	Observed		0	1	
Step 0	Injury	0	30	0	100.0
		1	14	0	.0
	Overall Percentage				68.2

a. Constant is included in the model.

b. The cut value is .500

Page 1



Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	-.762	.324	5.545	1	.019	.467

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	la_wve(1)	.074	1	.786
		AADT_K	8.489	1	.004
		Int_St(1)	1.179	1	.277
		Daylight(1)	.040	1	.841
	Overall Statistics		10.649	4	.031

Block 1: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	12.292	4	.015
	Block	12.292	4	.015
	Model	12.292	4	.015

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	42.751[a]	.244	.341

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Classification Table[a]

			Predicted		
			Injury		Percentage Correct
	Observed		0	1	
Step 1	Injury	0	29	1	96.7
		1	9	5	35.7
	Overall Percentage				77.3

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	la_wve(1)	.806	.826	.953	1	.329	2.240
	AADT_K	.197	.094	4.399	1	.036	1.217
	Int_St(1)	1.287	1.180	1.190	1	.275	3.623
	Daylight(1)	.381	.982	.150	1	.698	1.463
	Constant	-7.866	2.932	7.199	1	.007	.000

a. Variable(s) entered on step 1: la_wve, AADT_K, Int_St, Daylight.

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