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Effect on Asphalt Quality Due to Nighttime Construction

FINAL REPORT

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16. Abstract

The objectives of this project were to identify and analyze the nighttime paving traffic control standards in other states and compare the effects of daytime vs. nighttime paving on quality, safety, costs, and construction time. Surveys of various Department of Transportations (DOTs) and local contractors were conducted. The safety issues involved with nighttime paving in South Carolina, including workers and the travelling public and "reasonable detour" concept used by other states to determine the advantages and disadvantages of the process were investigated. In addition, the cost and the quality measurements of nighttime paving vs daytime paving (e.g., core compaction data, ride quality, overall pay factors, etc.) were studied and analyzed. The construction time of nighttime paving vs. daytime paving were measured. The data were gathered from various DOT districts around the state. The findings, in general, indicated that many states pay for mixtures used during night time paving. In addition, the survey responders indicated that many states do not keep track of many aspects and important information regarding this issue. The data from all districts of South Carolina indicated that, in general, the cost of mixtures used (per ton of mix) in night time paving is higher than day time paving operations. In addition, more accidents happen during night time paving vs day time paving.

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Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the presented data. The contents do not reflect the official views of Tri County Technical College, SCDOT, or FHWA. This report does not constitute a standard, specification, or regulation.

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1 Introduction

1.1 Problem Statement

In many areas of the state, traffic congestion places a serious burden on the public and, in some cases, affects the economic vitality of the South Carolina and the region. A major portion (in some cases as much as 10 to 24%) of this congestion is attributable to roadway construction and maintenance activities. One way to reduce the congestion effects of roadwork activities is to perform them during nighttime when there is a major reduced traffic demand. In one study, the data suggested that a third of the work zones present on national highway system roadways were active primarily at night. This compares to 58% of those work zones that were active during the day, and 9% of those projects that involved continuous work activities over both daytime and nighttime hours (Ullman 2004). In most cases around the state, traffic demand fluctuates over the 24 hour period. During the day, the traffic seems to be at the highest percentage compared to the traffic during the evening and early morning hours.

Although there are some obvious benefits to performing work activities at night, especially on high-volume roadways where any traffic-flow restrictions during the day can create serious congestion and delay, there are also multiple issues that can make night work a challenge including the following topics:

1.2 Quality of Work and Production

In general and depending on the task, working at night can have implications on work quality, production rates, and costs, and these factors might translate into higher cost for the SCDOT. For example, the effects of lighting on worker vision may reduce work quality. In addition, night work typically requires a cost premium for materials and labor in many cases around the state. At the same time, however, lower traffic volumes may make it easier and quicker for materials to be delivered to the job site. This can result in a potential increase in productivity and a potential reduction in overall construction costs.

1.3 Safety of Personnel

Several research project results have indicated that night work presents challenges to highway work crews. For example, one major issue is the lack of adequate lighting for the workers. Night work generally involves somewhat degraded vision for the workers. This is due to lower overall luminance levels in the work zone at night compared to daytime work. In addition, the shadows created by equipment, workers, and materials as well as the glare from vehicle headlights and equipment lights around the work area make the work place very challenging to manage safely. In addition, some research results have indicated concerns over potential degradations of workers' levels of attention and overall health. This is mainly due to the ongoing disruption of the natural circadian rhythms of the human body. One important factor that is often ignored is the effect of night work on workers' quality of life due to reduced social- and family-interaction opportunities, etc.

1.4 Safety of Traveling Public

Most of the research work in this area has identified several issues and problems related to the driving public including the following:

- Reduced visibility for drivers due to lower levels of light available at night, especially for older drivers with vision deterioration;
- Decreased driver expectancy for encountering road work activities at night;
- Higher percentages of impaired and/or drowsy drivers on the road at night compared to the daytime; and
- Higher traffic speeds approaching and traveling through the work area causing more potentially severe crashes.

1.5 Construction Nuisances

In general, night work can have a negative impact on adjacent neighborhoods and businesses that would either not be as disturbing or would not be experienced at all if the work were conducted during the daytime. The nuisances might include the following:

- The effect of construction noise on sleep patterns of nearby residents,
- Glare from temporary lighting systems intruding on nearby dwellings, and
- Lack of or limited access to businesses that operate primarily at night.

1.6 Summary

Many research projects have been conducted to investigate the hazards, demands, and nuisances of construction, including:

- Illumination requirements of nighttime work zones (El-Rayes and Hyari 2005a, El-Rayes and Hyari 2005b, Hyari and El-Rayes 2006a, Hyari and El-Rayes 2006b, Nassar 2008)
- Evaluation of construction nuisances during nighttime work zones (Schexnayder 1999, Schexnayder and Ernzen 1999)
- Evaluation of the impact of nighttime work zones on driver and worker safety (Arditi et al. 2004, Arditi et al. 2007)
- Quantification of the impact of nighttime operations on construction cost and quality (Lee and Thomas 2007, Al-Kaisy and Nassar 2005, Kumar and Ellis 1994)

The quality of the paved section and job productivity have many definitions that range from the appearance, rideability and smoothness of the finished project to how effective and safe workers are on the job and how many units of a construction product are produced in a certain time. For many years, the perception has been that construction productivity is impacted by working at night. Some suggest that the productivity of the workers will be decreased due to nighttime paving. Other research indicates that less traffic congestion is a major contributor to productivity improvement in nighttime construction. However, several research studies show that for many paving activities conducted during the night, productivity is not impacted in either direction. There are several issues that must be recognized when considering the productivity topic including the work-zone factors (WZF) and work management countermeasures (WMC). The WZF are the physical conditions and primarily deal with lighting. The WMC are the techniques used by the management team to ensure worker safety, productivity and physiological alertness (e.g., lack of sleep issues, etc.).

It is important that DOTs maintain the quality of nighttime construction operations. The FHWA also has national objectives on quality construction. These include improved system performance, decreased congestion, improved safety, and the impacts on several issues including: the environment; duration and disruption of traffic flow; and cost of the project. One of the most significant measures used to judge the quality of the pavements according to the National Quality Initiative (now the National Partnership for Highway Quality) is pavement smoothness. This research has resulted in development of several quality programs. One of these programs for concrete pavements is the FHWA's HIgh PERformance Concrete PAVing (HIPERPAV). These programs, in general, ensure that the long-term expectations are met by providing quality in highway and road construction. In addition, this will ensure the lowest maintenance and rehabilitation costs for the Agency. For many years, FHWA's National Highway Specifications have provided the guidelines and steps for construction project evaluation and assessment (e.g., pavement smoothness) (https://fhwapap04.fhwa.dot.gov/nhswp/).

A survey of 14 State DOTs was completed to try and determine the perception of factors that impact the quality of the final product. The survey indicated that some factors were perceived to possibly increase quality, while others were perceived to possibly reduce quality (Table 1-1). In most cases, adequate visibility and proper temperatures are required to produce quality nighttime asphalt paving projects. Nighttime work benefits from the lower traffic volumes and cooler temperatures. However, there are other factors impacting nighttime construction quality including:

- Inadequate lighting and poor vision;
- Human factors; and
- Insufficient amount of inspection and supervision.

In order to ensure reasonable smoothness for a nighttime paving project, the contractor needs to exercise extra care and quality control. There are several methods that are recommended to compare daytime versus nighttime paving quality. For example, Douglas and Park (2003) indicate that the three methods used by the Oregon Department of Transportation (ODOT) are International Roughness Index (IRI), Composite Pay Factor (CPF), and Overall Condition Index (OCI). In general, IRI measures the longitudinal pavement profiles to evaluate pavement condition and remaining life. CPF is used to measure, through statistical analysis, the quality of the material that contractors produce and use during paving, resulting in the anticipated performance and quality of the pavement. OCI measures the pavement condition such as the amount of rutting, cracking, raveling, and bleeding present on pavements.

Table 1-1: Survey Results for State DOT Perception of Factors Impacting Quality

Factor	Reduce Quality (%)	Same Quality (%)	Increase Quality (%)
Cooler temperature in night	50	36	14
Longer work hours at night	7	79	14
Lighting	86	14	0
Less interference of traffic	0	21	79
Quicker material deliveries	7	21	72
Allow more lanes to be closed	0	36	64
Increased duration of closed lanes	0	43	57
Effective communications among agency personnel, contract manager, and field staff	43	36	21
Availability and supply of materials and spare parts	57	36	7

2 Scope of the Research Project

2.1 Research Objectives

The major objectives of this project were to identify and analyze the nighttime paving traffic control standards in other states and compare the effects of daytime vs. nighttime paving on quality, safety, costs, and construction time. The specific objectives were the following:

1. Conduct a comprehensive literature review regarding this topic;
2. Conduct a national survey of all State DOTs regarding nighttime paving and related issues associated with this topic;
3. Conduct a survey of SC contractors regarding nighttime paving issues;
4. Investigate the safety issues involved with nighttime paving in South Carolina, including workers and the travelling public;
5. Investigate the "reasonable detour" concept used by other states to determine the advantages and disadvantages of the process;
6. Investigate the quality measurements of nighttime paving vs daytime paving (e.g., core compaction data, ride quality, overall pay factors, etc.);
7. Investigate costs of nighttime paving vs. daytime paving;
8. Investigate construction time of nighttime paving vs. daytime paving; and
9. Provide recommendations to SCDOT regarding options for nighttime paving that will optimize construction while limiting public inconvenience, such as traffic volumes for lane closure restrictions, detours, any other traffic control options identified during the study.

2.2 Organization of the Report

The contents of this report have been divided into several sections (chapters). Chapter 3 contains the literature review for many topics studied in this research project. Chapter 4 describes the experimental design used for this work. Chapter 5 contains the results of the research activities. Chapter 0 contains the conclusions and the recommendations for this research study. Several appendices contain additional raw data and results. The report also includes a partial list of references studied during this investigation.

3 Literature Review

A comprehensive literature review was conducted to investigate the effect of nighttime paving operations on various aspects of asphalt pavement construction, including work zone safety, cost, quality and nuisances.

3.1 Background

Louisiana DOT officials report that the night time paving increases the construction cost by 5 to 10 dollars a ton compared to day time paving. Some of the challenges that DOT faces during night time paving include the following:

- Road alignment;
- Mix issues such as segregation;
- Mix temperature – lumps;
- Truck beds not clean – can't see until too late;
- Distance between construction site and the plant (weather issues); and
- Fog.

They report the advantages as to include:

- Better production at night
- Less traffic to and from the jobsite
- Less interference from outside
- Less congestion at the plant when loading trucks
- Trucking has better "turnaround" time
- Rush Hour traffic avoided, morning and evening
- Cooler temperatures at night during summertime for workers.

According to Louisiana DOT officials; however, there are some disadvantages of doing the construction during the night time including the following:

- Cost
- Safety (Figure 3-1)
- Less light – only work area is lit (Figure 3-2)
- Can't see mat appearance as well (Figure 3-3)
- Mat segregation is harder to see (Figure 3-4)
- Wintertime presents problems with colder weather at night than daytime
- Rain "sneaks" up on crew at night
- Too much noise for some neighborhoods – Exceeds Local Ordinances (Figure 3-5)

They indicate that the problems at the plant will include the loader operator will have a hard time to see stockpiles to minimize the segregation. In addition, in some cases, staffing effectively is always a problem and the plant operator can't see outside components at plant as well as day-time. During the testing, there might be other issues including:

- Sampling mix is more difficult due to lighting;

- Need special lighting for sampling stand and area to assure safety and improve visibility; and
- QC personnel and LDOTD personnel cannot see cold feed operations as well.

On the roadway, the LDOT reported the following concerns:

- The knowledge of the paving crew regarding the paving plan;
- It is more difficult to keep the alignment straight;
- Matching the joint is more difficult because of poor visibility; and
- The workers can't see the mix in the paver and under the augers until it is behind the screed.

All of these issues could cause problems with the quality of the end product.

Figure 3-1: Nighttime Paving - Safety Issues

Figure 3-2: Lighting Issues During Nighttime Paving

Figure 3-3: Hard to See Mat Appearance - Nighttime Paving

Figure 3-4: Nighttime Paving - Possibility of Mat Segregation

Figure 3-5: Noise Issues - Nighttime Paving

According to a survey conducted by Hinze and Carlisle (Hinze & Carlisle, 1990), there are six important factors, when deciding on nighttime construction contracts, which must be considered: congestion, safety, noise, work time available, user cost, and quality.

A study conducted by Park, et al., listed the top five factors in decreasing significance: safety, traffic control, congestion, lighting, and quality (Park, Douglas, Griffith, & Haas, 2002). It is important to note that in both studies, contractors seemingly admitted that quality takes a backseat to other issues with regard to nighttime paving projects. This is important since there is no cost savings in conducting the work during the night; therefore, there is a possibility that work quality, in many cases, takes a back seat to other issues.

There are several knowledge gaps in the literature regarding the daytime vs. nighttime construction. The first is a lack of empirical evidence in determining whether or not nighttime construction has an impact on the quality of the finished work (Rebholz et al., 2004). The FHWA has also recommended a push in research of nighttime's impact, claiming that the ―current conclusions to date are inconclusive regarding the comparison of productivity and the quality of daytime and nighttime projects on roadways‖ (Abraham, Spadaccini, Burgess, Miller, & Valentin, 2007). There are some limited research studies performed concerning the impact of nighttime construction on work quality, but most of these studies used inadequate research methods or incomplete data sets‖ (U.S. Cong., 2007). For example, grading scale surveys are one of the most widely research methods used for investigating construction quality. However, these are subjective in their nature and can lead to skewed results (Northrup, 1996).

Hinze and Carlisle (Hinze & Carlisle, 1990) conducted a survey entitled Variables Affected by Nighttime Construction Projects. The results indicated that 76% of the project and resident engineers surveyed believed that the quality of asphalt concrete paving work performed at night was lower than the quality of similar work performed during the day. However, one question from the survey asked if there were any tasks performed better at night. For this question, no task mentioned received a majority; however, six responders (1/6 of the respondents) indicated asphalt concrete paving. So, in a study where an overwhelming majority in the study believes that paving quality is affected negatively by nighttime operations, approximately 17% believe that the quality is positively affected by the same circumstances. Hancher and Taylor (Hancher & Taylor, 2001) found that state DOT's and highway contractors see quality as the top problem encountered during nighttime construction. However, to add to the confusion, resident engineers rated quality third in the same study. This difference of opinions among engineers shows that empirical data is crucial for any conclusive research on the subject.

Rebholz et al., indicate that one major issue in investigating the quality of highway construction is that there is no single definition of construction quality for transportation projects around the country (Rebholz et al., 2004). In general, quality is defined as―the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs (Joint Technical Committee, 1994). The product, with respect to roadway construction, is the highway infrastructure. The service is the use of that infrastructure by all commuters and the needs are safety enhancement, congestion alleviation, traffic court relief, economic efficiency and growth, and military defense system enhancement (Weingroff, 2011). The pavement condition contains the features and characteristics of the pavement grouped together.

Hoque indicated that the serviceability and ride ability are the two key interrelated components when considering the concept of pavement condition with respect to the users (Hoque, 2006). According to Nighttime Construction: Evaluation of Construction Operations, the most important quality aspect of any pavement is surface smoothness (Rebholz et al., 2004). Serviceability is the ability of a pavement to provide the desired level of service to the drivers. Ride ability is the subjective comfort as experienced by the drivers using the pavements (Hoque, 2006). Many agencies around the country are including financial incentives and disincentives for the ride ability and surface smoothness requirements. (Boeger & Crowe, 2002). These requirements include some roughness measurements that affect vehicle dynamics and ride quality‖ (FHWA, 2005). In general, roughness readings worsen over time for roads due to deterioration of the pavement condition. This is caused by many factors including design inadequacies, traffic loading, material aging, construction deficiencies, and environmental factors (Hoque, 2006).

Deteriorations or pavement distresses can cause many issues with smoothness or ride ability. The following distresses can be caused by construction deficiencies: depressions, rutting, shoving, alligator cracks, longitudinal cracks, crescent shape cracks, delamination, flushing or bleeding, raveling, stripping, edge breaks, and edge drop-offs (Hoque, 2006). All of the above distresses that could affect the serviceability and the ride ability of the pavements when performing night time paving could be a major problem. This potential variability in road quality makes it very important issue when considering night time verses day time paving.

In general, working at night inherently affects the following variables in many ways, including visibility, worker fatigue, material availability, equipment availability, and weather and environmental changes (Hinze & Carlisle, 1990).

Visibility and worker fatigue have been the focus of many research studies and many information is available in literature. In general, poor visibility and worker fatigue, due to difficulties in quantification and mitigation, are largely affected by the decision to work at night. First, poor visibility affects many people on the job site including the paving laborers, but also the machine operators and inspectors. Many research projects have been initiated to study the potential problems due to lack of visibility and the minimum requirements and optimal lighting for construction tasks performed at night (Ellis, 2001; Hyari & El-Rayes, 2006).

R.D. Ellis suggests a minimum illumination level of 108 lux for paving and milling, as well as any activity involving the performance of visual tasks of medium size, or low to medium contrast, or medium required accuracy‖ (Ellis, 2001). For example, New York and Florida have determined their own lighting requirements in an effort to ensure quality nighttime construction as best as possible (Shane, Kandil, & Schexnayder, 2012). In many cases, though, agencies do not necessarily set standards for lighting and, thus, leaves the lighting tools and standards to the contractors' discretions. This, in some cases, might lead to less than optimum lighting arrangements (Shane, Kandil, & Schexnayder, 2012). If lighting is not adequate, and sometimes even when it is, mistakes in construction and operation could easily go unnoticed by inspectors and can cause as problems in pavement quality in the future.

In any industry, worker fatigue always has the potential to affect the quality of the end products. Physical and mental fatigue can cause workers to be less productive, more distracted, and more prone to making mistakes (Barton, 2009). In general, fatigued workers tend to exhibit a loss of concentration, the need to repeat tasks (budget issues), and in many cases slower work paces (Barton, 2009). This situation is due to the inversion of natural sleep cycles, which are based on circadian rhythms. According to the American Psychological Association, "All the sleep in the world won't make up for circadian misalignment" (Price, 2011).

Adolfo Ramirez, focal point of a Los Angeles Times piece on nighttime pavement workers, claimed that many workers don't do enough night work to get used to it, so the workers feel kind of sick all the time (Catania, 1993). In general, not enough research has been conducted directly studying fatigue on the construction site; however, studies focusing on fatigue in other industries can be related to construction worker fatigue due to the similarities in repetitive work tasks, use of heavy equipment and complex work processes‖ (Hallowell, 2010). Therefore, when a study of 200 production workers reveals that 52% admitted to making mistakes on the job due to fatigue from abnormal shift hours (Deros, Khamis, Ismail, & Ludin, 2009), it is an issue that the industry leaders must take it seriously. Specially, considering two-thirds of nighttime construction workers get less than six hours of sleep before their shifts, this becomes a major issue for the industry (Holguín-Veras et al., 2003).

Decision making tools have been used by many research teams to aid in determining whether night-work is conducive to the success of individual construction projects, based on the aforementioned effects and many other parameters that may be affected. For example, one study surveyed state agencies, contractors, and resident engineers and determined that two of the three groups believed that quality was the biggest problem encountered during night operations (Hancher & Taylor, 2001). In addition, the researchers asked what specific activities were negatively affected in terms of quality and productivity. The results indicate that the asphalt paving fell into the negatively affected quality category (Hancher & Taylor, 2001). Over 30 individuals, engineers to laborers, were surveyed, and resulted in several suggestions to help combat worker fatigue and cost problems associated with nighttime construction, including shorter work weeks, better pay differentials for night workers, temporary accommodations, and better evaluation of when to perform nighttime construction (Holguín-Veras et al., 2003).

In 2004, Illinois Department of Transportation’s study showed that all surveyed participants believed work quality was negatively impacted at night for all construction practices including resurfacing, surface treatment, milling and removal, and even pavement marking (Rebholz et al., 2004). Actually, resurfacing was ranked as most negatively impacted by nighttime construction. Still, there is not strong objective and scientific evidence to support a difference in quality (night time paving vs day time) to corroborate the valued perception of engineers and workers.

Grau, et al., investigated the relationship between nighttime construction scheduling and future road quality in terms of roughness. The research was conducted in three phases: 1) conducting interviews with local contractors and others; 2) on-site observations, and 3) analyzing historical data. Interviews and on-site observations were conducted to determine potential differences in the paving practices and general opinions in the paving industry regarding daytime versus nighttime paving. However, most of the information came from historical data and analyzing the data. In this research program, the differences in road quality (defined as pavement roughness) between day- and night-scheduled construction were determined by an analysis of the IRI (International Roughness Index) over the pavement lifecycle. This information was provided by the Alabama Department of Transportation.

Grau, et al., concluded that roads resurfaced at night rather than during the day are very likely to have significantly higher IRI values over time. Since pavements with the higher roughness values, in general, have more distresses and deteriorations; it is hypothesized that the cost of the maintenance for roads resurfaced at night will be much more. They also concluded that the main factors potentially contributing to the poorer night-paved quality and subsequent higher asphalt roughness indices include the following:

- Inconsistent inspection or lack thereof,
- Poor of illumination and low visibility, and

- Worker fatigue and difficulty remaining alert.

For many years, the state and federal transportation agencies demanded that many construction projects be conducted during nighttime. One major reason for this is the result of the need to alleviate increasing congestion. The 2011 Urban Mobility Report indicates that congestion caused urban Americans to travel 4.8 billion hours more and to utilize an extra 1.9 billion gallons of fuel for a congestion cost of $101 billion (Schrank, Lomax, & Eisele, 2011). One of the solutions proposed by the construction industry has been the night paving of major construction paving projects. State DOTs have increased the resources and expenditures on nighttime operations to alleviate the problem of congestion (El-Rayes & Hyari, 2005). As of 1995, the NY DOT has considered nighttime construction in its development of project specifications, and has also legally bound contractors and agencies to consider nighttime scheduling for urban projects in some parts of the state (FHWA, 2007b). New Jersey performed an estimated 25% of highway construction primarily at night according to survey data from 2001 (Holguín-Veras et al., 2003). Due to many reasons, one being congestions due to increased volume in traffic, nearly all major cities consider nighttime construction.

3.2 Safety and Traffic Management

A primary metric to measure any paving operation is safety of workers as well as the traveling public. Effective traffic speed control has long been known to be the biggest factor at reducing work zone incidents. Various speed control procedures and policies are reviewed in the subsequent sections for both nighttime and daytime paving operations. Furthermore, the types of incidents that occur can also yield insight into some of the factors at play. It will be shown through an extensive search of the literature that quantifying work zone incidents is exceptionally difficult due to the fact there is no consistent reporting mechanism. In some cases, incidents that do not meet a monetary threshold and cause no injury are not reported to police. In other cases, the actual location of the incident is unclear due to vehicles being moved out of work zone areas to reduce congestion.

3.2.1 Speed Control

There are numerous implementations of speed control devices and procedures. Signage is by far the most common method to alert drivers to an upcoming work zone and the associated reduction in the speed limit. Other methods of speed control involve the deployment of police, drone radar, and utilization of active speed feedback displays. Each of the techniques works with varying levels of success.

A survey done in 2003 (Benekohal et al. 2003) of 37 state DOTs indicated the effectiveness of certain signage. When asked about using signage specified by the MUTCD (FHWA 2012), 32% of DOTs stated they do not go beyond the specifications. The remaining DOTs indicated that they have used additional signage such as indication of double fines for speeding, specific road closure duration, duplicate signs on both sides of roadway, and directional signage to local businesses and points of interest. Furthermore, 70% of DOTs indicated they understood the factors that led to drivers ignoring the posted signage. Some of the factors included the failure to remove signage upon work completion, outright incorrect information, no enforcement, and too much signage.

In the same 2003 study, Benekohal et al. inquired as to the utilization of intelligent transportation systems (ITS) in work zones to regulate speed. Approximately 43% of DOTs indicated that they do not implement ITS technologies. Of the DOTs that do implement ITS, eight of them use variable message boards, five of them deploy portable variable message boards, and three implement travel time prediction systems. Other ITS technologies include real-time website updates, radio announcements, and traffic detection systems to monitor and react to varying traffic flow conditions.

A similar study conducted by Maze et al. (2000) found that only 7% of responding DOTs considered MUTCD regulatory signage to be effective at speed management. However, 70% of responding DOTs stated that police deployment was "very effective at imposing speed limit compliance [in] work zones". The survey also indicated that a fair number of DOTs utilize changeable message signs, including the ones that display the drivers speed. While not explicitly stated by DOTs, it is assumed these signs have some effect on driver speed otherwise the additional cost of deployment would not be worth it.

In terms of quantifiable data regarding the effectiveness of various speed control measures, there are numerous studies which examine factors relating to lane widths, signage, police presence, and combinations of these and other factors. Results from two older studies by Lyles (1981) and Benekohal and Shu (1992b) demonstrated that non-steady burn lighting had a meaningful impact on the traffic flow. The results from Benekohal and Shu (1992b) indicated that the average work zone speed for cars was reduced by 1.9 – 7.1 mph while there was a reduction of 1.3 – 6.0 mph for trucks. A more recent study has shown that modifying the simple blinking lights to a synchronized system (Figure 3-6) yielded more improvements over a steady burn or random blinking system (Finley et al. 2001). It should be noted that when considering lighting as a stand-alone option, the most effective systems are ones that are dynamic (e.g. blinking, strobing, synchronized). McAvoy et al. (2006) found that steady-burn lights had no measureable impact on work zone compliance or notification. It was noted in the study that at the time, only six states utilized steady-burn lights on drums in work zones.

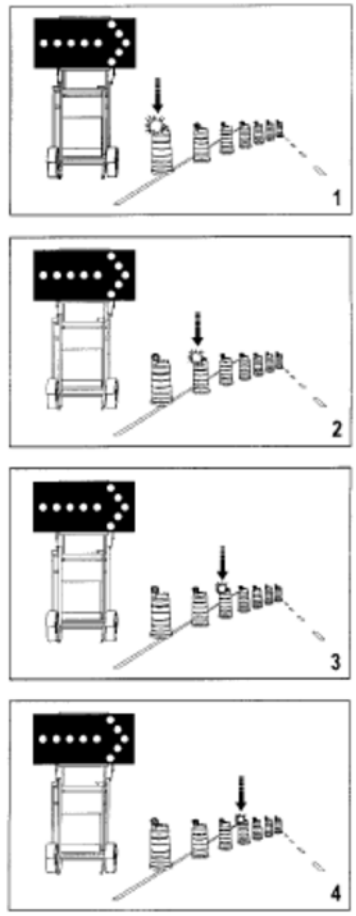


Figure 3-6: Synchronized flashing light system indicating upcoming taper (from Finley et al. 2001).

3.2.1.1 Nighttime Speed Control

One of the most detailed analyses of speed control factors in nighttime work zones was conducted by Miller et al. (2009). In the study, seven construction sites were visited that utilized a combination of the three following speed control procedures: MUTCD signage, updateable message signs, and police deployment. In order to measure speed values without influencing the drivers, the researchers disguised their vehicle as a construction vehicle and utilized a laser speed gun so as not to set off radar detectors. There were almost 2,800 individual speed readings obtained from the seven construction sites during a time period from 21:30 to 03:30. The vehicle type (car/van/SUV/pickup/box truck/semi-truck) was recorded with each speed reading. More details about each site are presented in Table 3-1.

Using a Seemingly Unrelated Regression (SUR) estimation, several trends were noted. It was found that the work zones with two lanes open had a mean speed approximately 8 mph faster than those with only one lane open. Additionally, when the original speed limit was 65 mph or faster, the mean speed was approximately 4 mph faster than those work zones where the original speed limit was less than 65 mph. Finally, for each 1% of semi-trucks present in the traffic flow, the mean speed decreased by 0.1 mph. On average, semi-trucks comprised 54% of the traffic flow and thus a speed decrease of approximately 5 mph was seen.

With respect to speed control options, the presence of police decreased the mean speed by approximately 5 mph, as seen in other literature (Benekohal et al. 1992a, Maze et al. 2000). The study, however, does not indicate how the police were deployed. For example, there would be a difference if the police car(s) sat with flashing lights as opposed to simply being parked. Finally, in line with numerous agency surveys, the presence of MUTCD signage or the presence of updateable signs had a statistically insignificant impact on the average traffic speed.

Table 3-1: Breakdown of construction site characteristics (Miller et al. (2009)

Site	1	2	3	4	5	6	7
Total Directional Lanes	2	3	3	2	3	2	3
Open Directional Lanes	1	1	2	1	2	1	1
Original Speed Limit [mph]	70	55	65	65	55	70	50
Work Zone Speed Limit [mph]	45	45	45	45	45	45	50
Number of MUTCD Signs	4	2	3	4	2	3	0
Number of Updateable Signs	0	2	1	1	1	0	1
Police Deployment	Yes	No	No	No	Yes	No	No

3.2.1.2 Daytime Speed Control

An extensive study examining the effectiveness of various speed control devices during the daytime was conducted by the Colorado Department of Transportation (Outcalt 2009). This study was unique in that CDOT setup a dummy work zone complete with construction equipment so that workers would not be in danger during the study. There were six speed control methods employed on a section of highway with a speed limit of 75 mph (

Table 3-2). It should be noted that when the police started writing tickets, they did so upstream of the work zone and thus no one had a speed greater than 5 mph through the work zone.

The results from this study again confirm that police presence has the most profound impact on traffic speed. It was also seen that a speed reduction of 30 mph was too drastic and had the highest non-compliance rates. This effect is known to many agencies and nearly every state limits the difference in speed limits between 10 to 20 mph (Migletz et al. 1999 and Maze et al. 2000). The non-compliance stems from the fact that with such a large drop in speed, the traffic flow becomes unstable as each driver decelerates at a different rate.

Table 3-2: Summary of speed control study using various speed control measures

(Outcalt, 2009)

Method	MUTCD Signs + Arrows	+Radar Speed Display	Police, light-bar on	2 Police, no lights	2 Police, writing tickets	MUTCD Signs only	MUTCD Signs only
Work Zone Speed Limit [mph]	55	55	55	55	55	65	45
85th Per. Speed [mph]	56	57	56	55	54	67	55
Mean Speed [mph]	50	51	50	49	47	59	48
> 5 mph Over	2%	3%	2%	1%	0%	2%	30%

3.2.1.3 Summary of Speed Control Issues

From the literature, it appears that speed control methods is not significantly influenced by the time of day with respect to the control method that offers the greatest compliance. The overall consensus is that police deployment is the best option for speed control in any work zone for both day and nighttime hours. However, this is usually the most costly option. Other methods such as changeable message signs do have an impact but the effects can vary.

3.2.2 Crash Data

Recent national crash data has shown that on average there are 750 fatalities and over 40,000 severe injuries resulting from crashes in and around work zones yearly (El-Rayes et al. 2013). Furthermore, 30% of work zone crashes involve construction workers (Mohan and Gautam 2002). The data from state to state varies somewhat due to the nature of construction procedures outlined by each state DOT and reporting procedures of local and state police agencies. In this section, crash data from four states (Illinois, Florida, Kansas, and Texas) will be reviewed. These states were chosen due to the availability of detailed analyses of their crash data.

3.2.2.1 Illinois

A 2001 research study by Raub et al. indicated that there are numerous factors contributing to work zone crashes. Non-compliant setup of traffic control plan, weather, and lighting conditions all have an impact on the likelihood of a crash. Examining data from the Illinois Department of Transportation for 1994 and 1995, Raub et al. (2001) found that crashes in work zones are most common on Fridays. The authors attributed this to driver fatigue at the end of the work week as well as higher overall congestion. It was also noted that crashes during the weekends dropped significantly. However, it was thought that this was more of an effect of police officers not classifying the crash as a work zone related incident if there were no workers present. Furthermore, many construction sites were noted to have lane and speed restrictions relaxed on the weekend.

The survey of crash data further revealed that the most common time period for a crash is between 3pm and 6pm (22% of all crashes). Crashes during the nighttime hours, which are between 9pm and 6am, account for approximately 21.5% of all crashes. It should be noted that the traffic flow during the nighttime hours is significantly less than the end of work day period from 3pm to 6pm. Raub et al. (2001) note that at the time, IDOT did not collect traffic count data for work zones so it is impossible to tell whether or not the afternoon versus nighttime difference is significant. Based on historical data, it can reliably be assumed that the nighttime traffic count would be much less than the daytime.

It has been noted that in Illinois it is extremely difficult to accurately make assessment of crash data (O'Day 1993; Pfefer et al. 1996) due to reporting statutes. If there is only property damage and it is below a certain threshold and/or the vehicle does not require a tow, there may never be a police report filed in the state crash database. Earlier work has indicated that as much as 75% of damaged property incidents and 50% of injuries not requiring hospitalization go unreported (Hauer and Hakkert 1988). It is likely other states have similar issues.

3.2.2.2 Florida

A 2008 study by Harb et al. examined crash data in Florida from 2002 to 2004. In 2004, Florida was ranked second in fatal work zone related crashes only following Texas (Harb et al. 2008). The analyzed data indicated that there is a higher probability of a crash occurring during nighttime hours (Table 3-3). Upon further analysis of the data, the difference between nighttime and daytime crashes can statistically be verified (Figure 3-7). The relative accident involvement ratio (RAIR) is a statistical characterization of the effect each parameter has on the crash data (Stamatiadis and Deacon 1997). The fact that the daytime RAIR is lower than the nighttime RAIR (**Error! Reference source not found.**) indicates that daytime work zones are statistically less likely to have a crash when keeping other factors constant for single vehicle accidents. When analyzing two vehicle accidents, Harb et al. (2008) provided a more detailed analysis with respect to the time of day (Figure 3-8). Again, crashes were more likely to occur at night, even with additional lighting, than during the day or even at dusk or dawn.

Table 3-3: Crash data for single and two vehicle work zone accidents (Harb et al., 2008)

Time	Single Vehicle Accidents	Two Vehicle Accidents
Daytime	22 %	13%
Dusk/Dawn	23%	20%
Nighttime (without lighting)	4%	3%
Nighttime (with lighting)	51%	64%

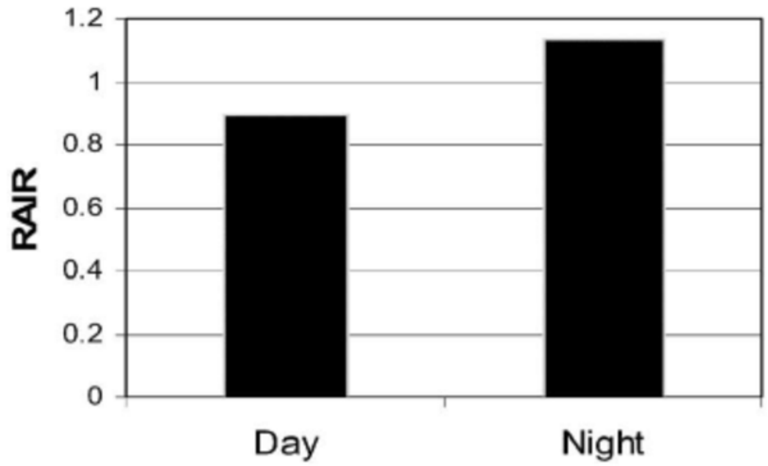


Figure 3-7: Relative accident involvement ratios (RAIR) for day and nighttime crashes in work zones for single vehicle accidents (Harb et al. 2008)

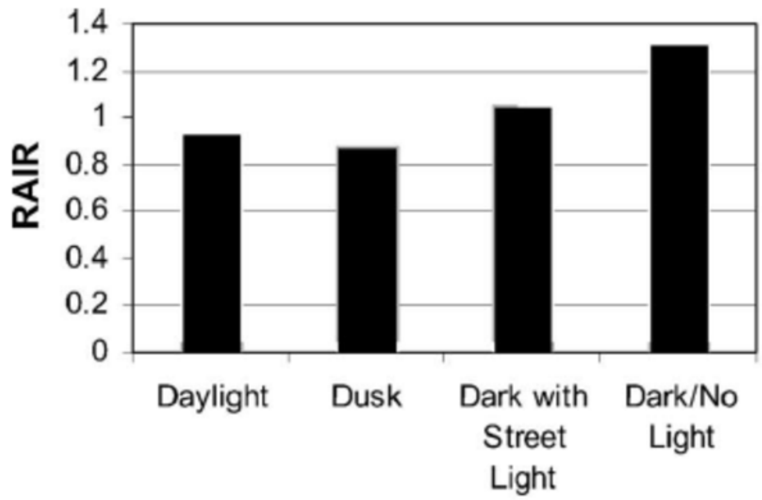


Figure 3-8: Relative accident involvement ratios (RAIR) for various times of day in work zones for two vehicle accidents (Harb et al. 2008)

3.2.2.3 Kansas

A study by Bai and Li (2006) examined 157 fatal work zone crashes in Kansas between 1992 and 2004. The researchers divided the data into four time periods: 06:00 – 10:00, 10:00 – 16:00, 16:00 – 20:00, and 20:00 – 06:00. Different durations were selected to account for peak and non-peak traffic conditions. The raw data (Table 3-4) indicates that there are two periods in which there is greater accident potential, mid-morning to mid-afternoon and throughout the night. It should be noted that the researchers did not have traffic count data and even stated that it was likely the nighttime accident count was for a much lower traffic volume. The study also examined the effect that the day of the week had on crashes and no statistical inferences could be made.

Table 3-4: Crashes resulting in fatalities in Kansas between 1992 and 2004 (Bai and Li, 2006)

Time	Duration	No. of Crashes	Percent
06:00 – 10:00	4 hrs	22	14
10:00 – 16:00	6 hrs	51	32
16:00 – 20:00	4 hrs	26	17
20:00 – 06:00	10 hrs	58	37

When only considering light levels, Bai and Li (2006) found that there was equal chance for a crash to occur in daylight or twilight/nighttime conditions. Another interesting finding was that 91% of all fatal crashes occurred when there were no adverse (e.g. rain, snow, fog, etc.) weather conditions. The researchers noted that drivers are generally more cautious in adverse conditions.

3.2.2.4 Texas

A study by Ullman et al. (2004) echoed some of the findings of the Illinois study (Raub et al. 2001) in that crash data was difficult to come by and was information deficient. Due to delays in the states database reporting schedules, the authors could only analyze data from 1998 – 2000. Furthermore, due to the size of the state, not all transportation districts utilized nighttime paving. In order to reduce any bias in the data, the analysis was separated between districts that perform "rare" night work and those that perform "significant" night work (Table 3-5). The results seem to indicate that nighttime paving has a lower crash potential. However, similar to other states, no traffic count data is available. It can safely be assumed that the traffic volume at night is lower than during the day. Furthermore, the authors state that the time period being investigated was when TxDOT decided to begin implementing more nighttime paving operations. The simple lack of work zones could have contributed to the lower number.

Table 3-5: Crash data for work zones in Texas. Adapted from Ullman et al. (2004).

Category	Daytime Work Zone Crashes	% of Crashes that are Severe	Nighttime Work Zone Crashes	% of Crashes that are Severe
Rare Nighttime Work	4,903	61%	1,545	64%
Significant Nighttime Work	15,806	67%	6,801	62%

3.2.2.5 Summary of Crash Data

In general, nighttime paving tends to have less total work zone crashes than daytime paving, though there are exceptions. However, all of the studies indicated that without reliable traffic counts, it is impossible to calculate a percentage of crashes from total traffic. It can be reliably assumed that nighttime traffic counts would be less than daytime counts. If this assumption is used, then nighttime paving is generally more accident prone as a function of traffic volume than daytime paving.

3.2.3 Detours

Sometimes projects require detours as the scope of the construction makes it unsuitable to maintain traffic flow. In these cases, great care is taken to ensure that the detour can handle the expected traffic volume and is the least disruptive to the area. Sometimes the detour can be suggested and others it can be forced.

A novel and highly effective approach was recently tested and modeled on I-81 in Virginia by the Virginia Department of Transportation (Gallo et al. 2012). The 3.7 mile, two-lane section was so badly deteriorated that a full depth reclamation was chosen as the rehabilitation procedure. The section under repair averaged 21,000 vehicles per day (vpd) with trucks comprising 30% of that volume. VDOT estimated that it would cost $40 million to implement conventional traffic management policies such as adding additional lanes and widening overpasses. The detour system that was selected needed to achieve a minimum compliance of 10% in order to maintain manageable delays.

To accomplish this, VDOT implemented several modifications to the typical detour management policy. Drivers were not alerted to the upcoming detour, and only simple signage indicating a work zone was ahead was deployed. As drivers approached the construction zone, the wording on the signage in most cases was intentionally vague so that some drivers were forced to utilize the detour. Finally, the utilization of a backup detour and activation of forced detour for cars was implemented aggressively to achieve a zero delay work zone.

VDOT sectioned the interstate so that the right lane was forced to exit just before the construction zone. The left lane was allowed to continue through the zone, albeit at reduced speed. When traffic was light, variable message signs were updated to state “Trucks Use Left Lane/Right Lane Exits”. This forced trucks to continue through the construction zone and not have to deal with getting off and on the interstate if they had taken the detour. If sufficient trucks were entering the work zone and a queue began to form, cars would stay in the right lane hoping to pass the trucks. If they remained in the right lane, they were forced onto the detour, thus reducing the queue potential around the work zone.

At times of heavy traffic, the variable message signs were updated to state “Trucks Use Left Lane/Cars Use Right Lane”. This forced more cars to utilize the detour and reduce the queue length at the start of the construction zone. This segregation effect can be seen in Figure 3-9. The segregation effect was extremely effective in that 90% of trucks remained on the interstate. Furthermore, there was a compliance rate of approximately 45% which far exceeded the minimum 10% needed to maintain manageable delays. After the project was completed, the hybrid detour system as well as the other detour options were modeled (Figure 3-10). It was clearly evident that the hybrid system outperformed any other option available.

Another study examining two-lane highway resurfacing operations found that detours provide significant benefit to the project (Chen et al. 2005). From simulations, it was found that full detours in one direction provided the lowest overall cost when considering user and agency costs. When compared to closing one lane at a time, the full closure and detour had a 2% decrease in overall cost. While not seemingly significant, this decrease accounts for the additional costs associated with setting up and maintaining a detour. The authors note that generally detours are more effective for nighttime construction due to the lower congestion on the detour route.

When comparing field observations to computer simulations, Collura et al. (2010) found that detours in one studied location performed well (Table 3-6). The data from SR-9 near Hadley, MA shows that with a detour, the travel time is reduced by about 32%. While some locations may not be suitable for the use of detours, their use can have a profound impact on the delay perceived by the user.

Table 3-6: Comparison of travel time and average speed on SR-9 near Hadley, MA (Collura et al., 2010)

	No Work Zone	Work Zone, No Detour	Work Zone, Detour
Travel Time (min)	21.3	40.5	27.6
Average Speed (mph)	15.11	3.4	14.9

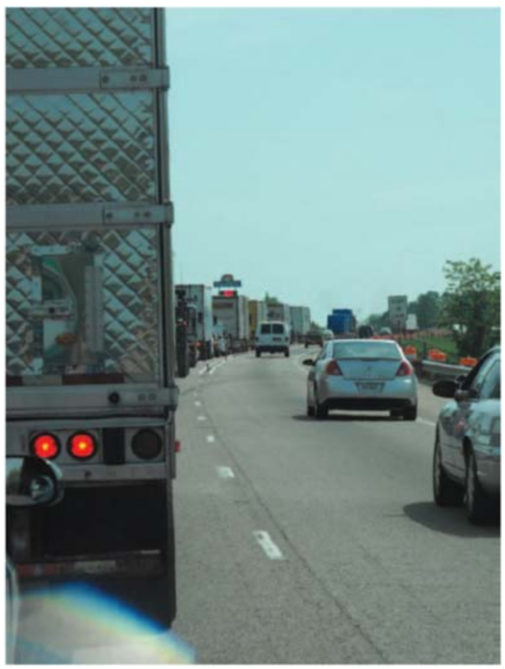


Figure 3-9: Segregation of truck and car traffic from hybrid detour system (Gallo et al., 2012)

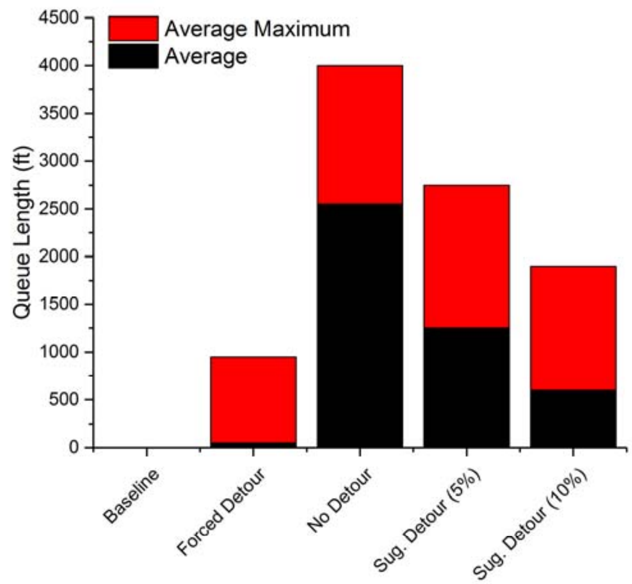


Figure 3-10: Peak-hour queue lengths for construction zone approach. The baseline indicates no construction zone present (Gallo et al., 2012)

3.3 <u>Paving Logistics</u>

A general concern in any construction project is the ability to maintain material flow and worker availability. Sometimes nighttime paving is selected so that material delivery is less likely to be delayed by traffic. Other times, daytime paving is chosen so that there is a greater availability of skilled workers to complete the project. This section examines the real world effect that daytime and nighttime paving operations have on material and worker logistics.

3.3.1 Worker Health and Performance

In general, night shift activities are harder both psychologically and physiologically for workers. A human's circadian rhythm, which regulates periodic bodily processes such as temperature, pulse, and blood pressure, is disrupted with night shift activities (Carpentier and Cazamian 1977). The circadian rhythm of humans are tied to the day-night cycle with active periods corresponding to daylight hours. Deviations from this natural cycle exerts stress on the body. Furthermore, changing back and forth between day and night shift activities exerts even more stress on the body as the circadian rhythm is never fully establish and continually disrupted. This stress was found in numerous studies to lead to poorer health and higher risk for disease.

A review of 17 studies on the link between night shift work and cardiovascular diseases found that there is an additional 40% increase in developing cardiovascular diseases in workers that perform night shift work (Bøggild and Knutsson 1999; Knutsson 2003). Another study followed 79,000 nurses over a period of 4 years and found a positive link between night shift work and coronary heart disease (Kawachi et al. 1995; Knutsson 2003).

While not proven conclusively, night shift work has been tentatively linked to a slightly higher risk for developing diabetes. One study investigated 300 refinery workers in Austria and found a 3.5% prevalence in night shift workers compared to 1.5% prevalence in day workers (Köller et al. 1978). A study in Japan found that the prevalence rate of diabetes for night shift workers was 2.1% compared to day workers who only had a 0.9% prevalence rate (Mikuni et al. 1983). The same study that followed the 79,000 nurses for 4 years also found that the prevalence of diabetes increased as the amount of night shift work increased (Kawachi et al. 1995).

Another issue in terms of worker health with respect to nighttime paving operations is the ability to get sufficient sleep. It is generally difficult for humans to sleep during the day due to the body's circadian rhythm and from external effects such as light, noise, and heat. A recent study showed that only 3% of workers on a permanent night shift had a complete transformation of their circadian rhythm to a nocturnal cycle and only 25% of workers had any substantial change in their circadian rhythm (Folkard 2008). Lack of sleep can result in workers experiencing symptoms such as insomnia, hunger, reduction in reaction time, and general loss of alertness (Carpentier and Cazamian 1977; Baker et al. 2001). Approximately 20% of night shift workers in the U.S. report having some sort of sleeping disorder or health issues arising from sleeping disorders (Baker et al. 2001). Furthermore, sleeping during the daytime can lead to relationship stress as the worker is unable to participate as much in family and social activities as they normally would be able to with a traditional work schedule (Baker et al. 2001).

3.3.2 Productivity

There are only a handful of studies that examine the productivity differences between day and nighttime paving operations. A comparison of daytime and nighttime paving operations in Florida indicated that there was no substantial difference in production rates between the two time periods (Ellis et al. 1993). However, this study examined is not entirely conclusive due to the fact that the daytime construction site was different from the nighttime construction site. Another study used a similar method to calculate the productivity difference. Douglas and Park (2003) compared 16 daytime construction sites and 17 nighttime construction sites. They found that the average tonnage for the daytime site was 164 tons per hour while the nighttime average rate was 202 tons per hour. Again, this study suffers from the same issue as the Ellis et al. (1993) study in that the construction sites are not the same.

A more illuminating study in Washington State compared the production rates for daytime and nighttime paving operations on the same site (Dunston et al. 2000). This was possible since there was a weekend closure of the highway for construction. It was found that there was no difference in the productivity between daytime and nighttime paving operations. Another study conducted on a fast-track reconstruction project on part of the I-710 highway in California had the similar opportunity to monitor both daytime and nighttime construction productivity on the same site (Lee et al. 2006). Furthermore, the closure was repeated for seven weekends so that an average trend could be established. It was found that overall the nighttime paving productivity, defined in the paper as times between 7 p.m. and 7 a.m., was about 10% less than the daytime productivity. It was noted that construction of the subbase was approximately equivalent in terms of productivity and that the final HMA layers were the source of the decrease in productivity for the nighttime hours.

In another study by the same authors, it was found that in two additional fast-track projects in California that there was no appreciable difference between daytime and nighttime paving operations in terms of productivity (Lee et al. 2007). The authors did note that major modifications to the schedule were needed when cool nighttime temperatures caused compaction issues with the asphalt concrete layers.

3.3.3 Quality Control

A major concern for agencies deciding between daytime and nighttime paving operations is the quality of the construction. Poor lighting and cooler temperatures at night can increase errors and in the case of asphalt pavements, cause poor compaction. Congestion during daytime construction can delay delivery of materials. The empirical evidence for quality in both daytime and nighttime pavement operations is sparse due to the lack of a unified definition of "quality". The majority of the literature uses international roughness index (IRI) data to estimate the quality of the pavement, with higher IRI numbers indicating the greater potential for durability problems in the future.

One of the more thorough examinations of the differences in quality between daytime and nighttime paving was a UTCA report (Grau-Torrent et al. 2013). Data, in the form of IRI measurements, from 49 daytime construction projects and 39 nighttime projects was analyzed. For projects that were new up to 30 months old, the IRI values between daytime and nighttime sites showed no statistical difference (Table 3-7 and Figure 3-11). However, for older projects, the difference between daytime and nighttime construction becomes more apparent. In projects that were 31 to 60 months old, the differences become statistically significant (Table 3-8 and Figure 3-12). Furthermore, the variation of nighttime projects increases compared to daytime construction. This trend continues for the oldest projects examined in the study (Table 3-9 and Figure 3-13). The nighttime IRI measurements increase by approximately 25% while the variation of IRI between projects increases by approximately 100%. These large increases clearly demonstrate a consistent trend of lower quality construction from nighttime paving operations.

The aforementioned findings are confirmed by the findings of Dougan (2001). After analyzing over 8,000 IRI measurements from multiple daytime and nighttime project sites, Dougan (2001) found that new construction showed little IRI difference between the two construction time periods (Figure 3-14). As with the data from Grau-Torrent (2013), the standard deviation between daytime and nighttime projects was similar in the results from Dougan (2001). Examining the older construction data, it is clear that the nighttime paving operations had a detrimental effect on the roughness (Figure 3-15). Furthermore, the standard deviation of the nighttime paving data was significantly higher than the daytime data. This suggests that the nighttime paving operations, in addition to having a higher overall roughness at later ages, experiences more variability between projects and even within the same project.

Table 3-7: IRI values for sites that are up to 30 months old. From Grau-Torrent (2013).

Site Type	Num. of Values	Average (in/mi)	St. Dev. (in/mi)
Daytime	41	60.29	17.32
Nighttime	43	62.22	15.18

Table 3-8: IRI values for sites that are 31 to 60 months old. From Grau-Torrent (2013).

Site Type	Num. of Values	Average (in/mi)	St. Dev. (in/mi)
Daytime	34	67.03	17.84
Nighttime	30	76.49	29.90

Table 3-9: IRI values for sites that are 61 to 90 months old (Grau-Torrent, 2013)

Site Type	Num. of Values	Average (in/mi)	St. Dev. (in/mi)
Daytime	25	72.09	15.81
Nighttime	27	89.87	32.19

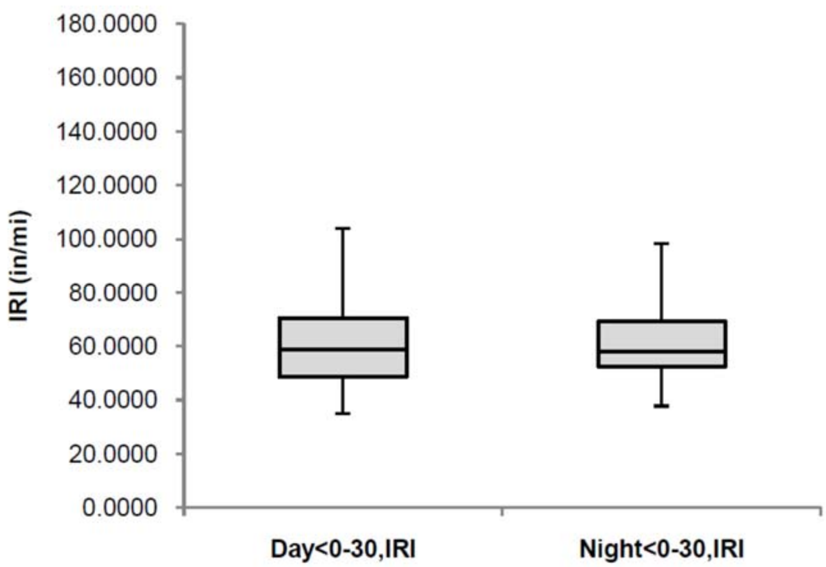


Figure 3-11: Statistical comparison of IRI values for sites that are new to 30 months old (Grau-Torrent, 2013)

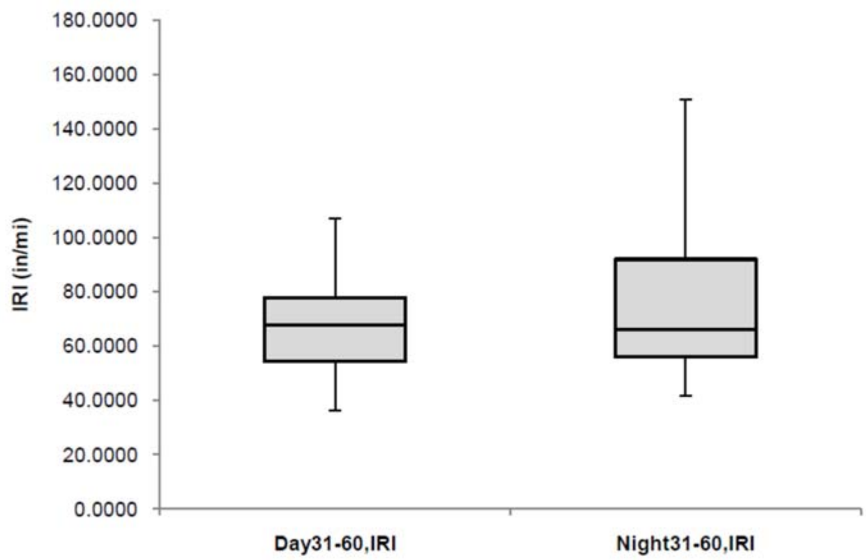


Figure 3-12: Statistical comparison between sites that are 31 to 60 months old (Grau-Torrent, 2013)

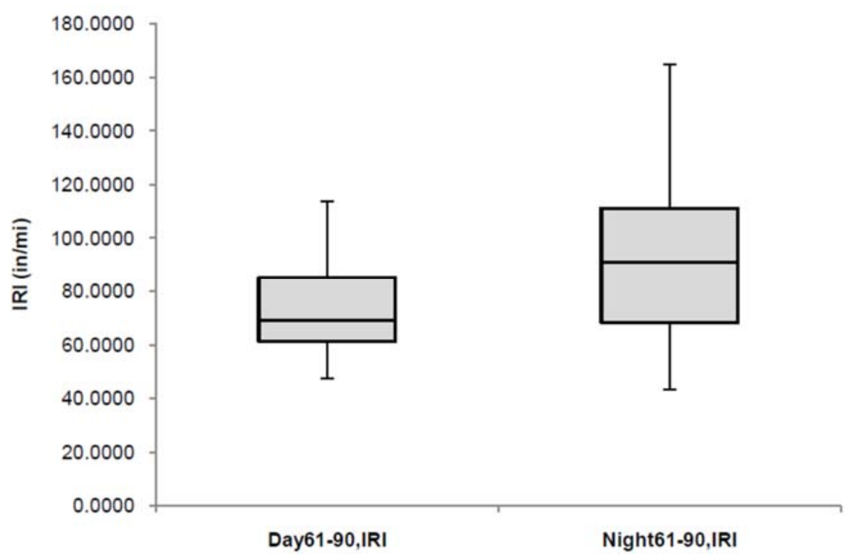


Figure 3-13: Statistical comparison between sites that are 61 to 90 months old (Grau-Torrent, 2013)

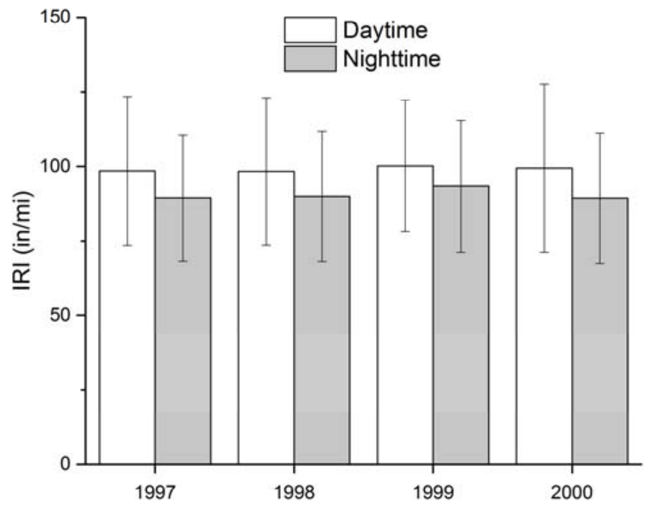


Figure 3-14: Comparison of daytime and nighttime new construction IRI values in Connecticut over a four year period (Dougan, 2001)

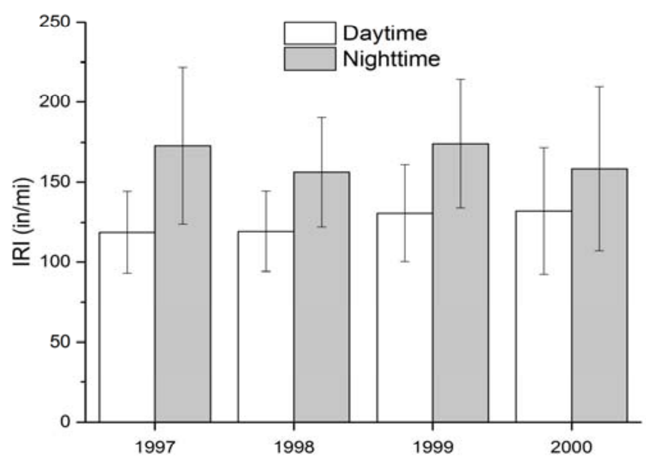


Figure 3-15: Comparison of daytime and nighttime old construction IRI values in Connecticut over a four year period (Dougan, 2001)

The quality of a pavement is not solely dictated by the IRI number. Achieving the correct compaction density will ensure proper air void content and produce a durable material. However, compaction efforts can be significantly affected by temperature differentials both to and on the site. It was found that in Washington State that the asphalt mixtures traveling to a construction site from a batch plant at night could develop a cooler crust of material in the truck bed (Read 1996). This led to cyclic compaction issues and areas that never achieved the correct density. Furthermore, it was found that the majority of all asphalt construction that experienced cyclic compaction issues occurred during night paving operations or at the beginning and end of the construction season.

The Washington state DOT decided to reexamine the findings from Read (1996) and conducted a more thorough investigation into the effects of paving temperature differentials (Mahoney et al. 2001). In this study, several sites were closely monitored during construction to see what key effects play into the cyclic compaction issues seen previously. Using a thermal camera, the researchers found that some areas during night paving operations experienced temperature differentials approaching 70F (Figure 3-16). There were also areas that had high temperature differentials during the daytime (Figure 3-17). There is not enough nighttime data in the study to see a clear trend but the initial impression is that the cooler nighttime temperatures slightly increases the average compaction temperature differential. It was found that over 40% of the sites studied in the report, both daytime and nighttime projects, had temperature differentials over 25F. Furthermore, the researchers note that random sampling is insufficient to detect these areas of poor compaction.

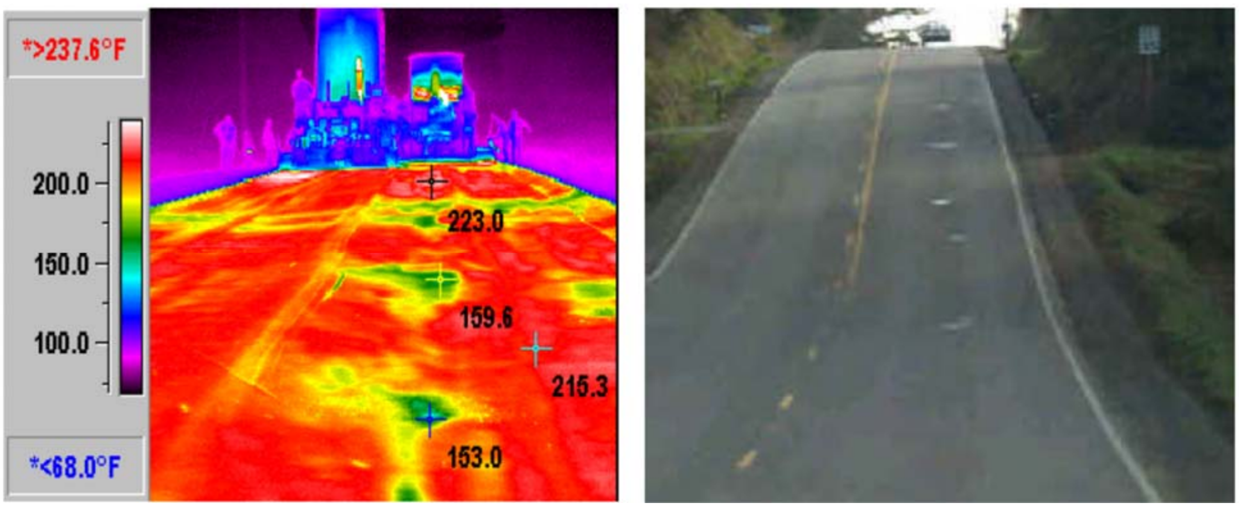


Figure 3-16: Compaction temperature differentials (left) and real image (right) of same location after construction (Mahoney et al., 2001)

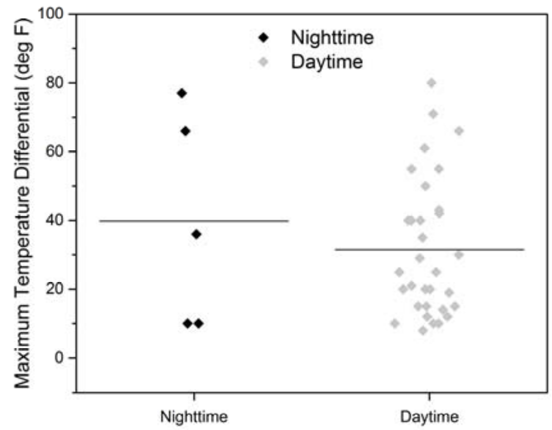


Figure 3-17: Comparison between nighttime and daytime asphalt mixture temperature differentials after initial screeding (Mahoney et al., 2001)

4 Experimental Design

The main objectives of this project included analyzing the effects of daytime vs. nighttime paving on various aspects of asphalt paving projects, including safety, costs, quality and construction time in addition to investigating options utilized by other states and providing recommendations to SCDOT regarding options for nighttime paving. In order to meet these objectives, the researchers collected and analyzed data from various sources described below. Figure 4-1 shows a flowchart of the data collection process.

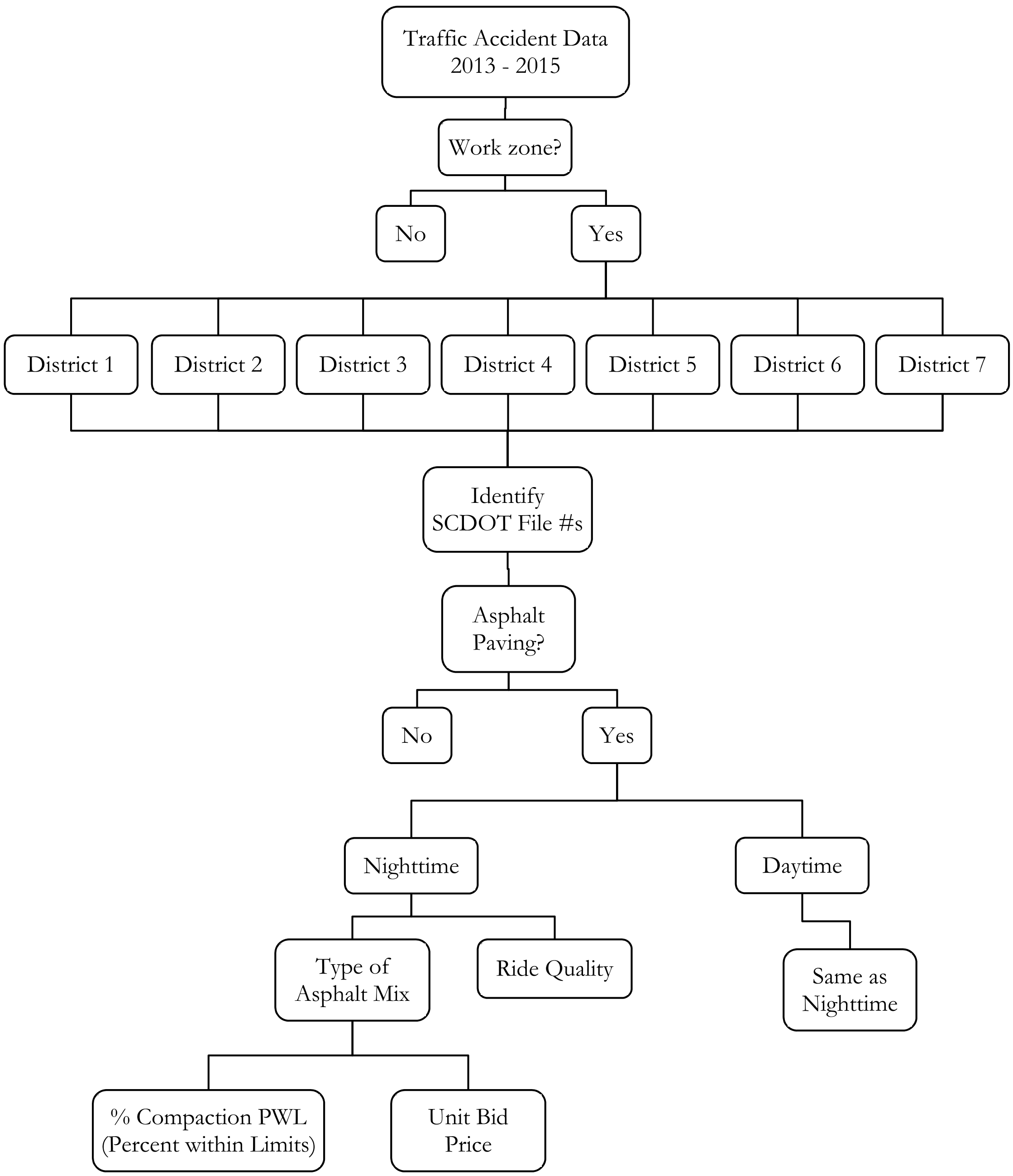


Figure 4-1: Flowchart of Data Collection Process

4.1 Literature Review

A comprehensive literature review was conducted to determine the findings of research activities on this topic around the country. During the literature review, special attention was given to identifying and analyzing the nighttime paving traffic control standards in other states and to compare the effects of daytime vs. nighttime paving on quality, safety, costs, and construction time.

4.2 State DOT Survey

A comprehensive survey of all state DOTs was conducted to establish the state-of-the-art lane closer and other traffic control practices. The survey was developed with input from the Steering Committee. The findings of the survey was used to establish the base lines and starting points for the development of the next steps. The survey questions are shown in Appendix A.

4.3 SC Contractors' Survey

A comprehensive survey of South Carolina Asphalt Pavement Association's (SCAPA) member contractors was conducted to establish some base lines for additional objectives of the project, including quality, costs, safety and construction time. The survey was developed with input from the Steering Committee. The survey questions are shown in Appendix B.

4.4 Safety Issues

An investigation of the safety issues involved with nighttime paving in South Carolina, including both workers and the travelling public was conducted. Information from the contractors' survey and traffic accident data from the South Carolina Highway Patrol was utilized to determine the safety issues related to nighttime paving in South Carolina and the potential solutions to many of the safety parameters.

The GPS coordinates for each accident were plotted graphically on maps for each of the seven Districts. Because the SC TR310 form used to collect accident data by the South Carolina Department of Public Safety does not indicate the type of work zone, all of these data points were not necessarily accidents that occurred in asphalt paving work zones. Some of these accidents could have occurred in work zones for utility work, mowing, other maintenance work, etc. However, larger groupings of accident data points indicated the likelihood of a work zone that existed for a longer duration, as would occur in an asphalt paving project. As such, these grouped accident data points in each District were identified as likely asphalt paving work zones during the initial phase of data sifting.

Figure 4-2 shows all work zone accidents in District 1 for 2012-2014 as well as the accident groupings of likely asphalt paving work zones for District 1 for 2012-2014. The red dots indicate the location of accidents that occurred in SCDOT work zones in 2012, the blue dots indicate the location of accidents in 2013, and the green dots indicate the location of accidents in 2014. Additional maps of the accidents and work zones for the other six Districts are shown in Appendix C.

The SC TR-310 form was used to mine some of the data. This form (Appendix D) is used by the Highway Patrol officials who complete the information at every accident. All the information then is entered into the SCDOT Traffic Engineering Safety database.

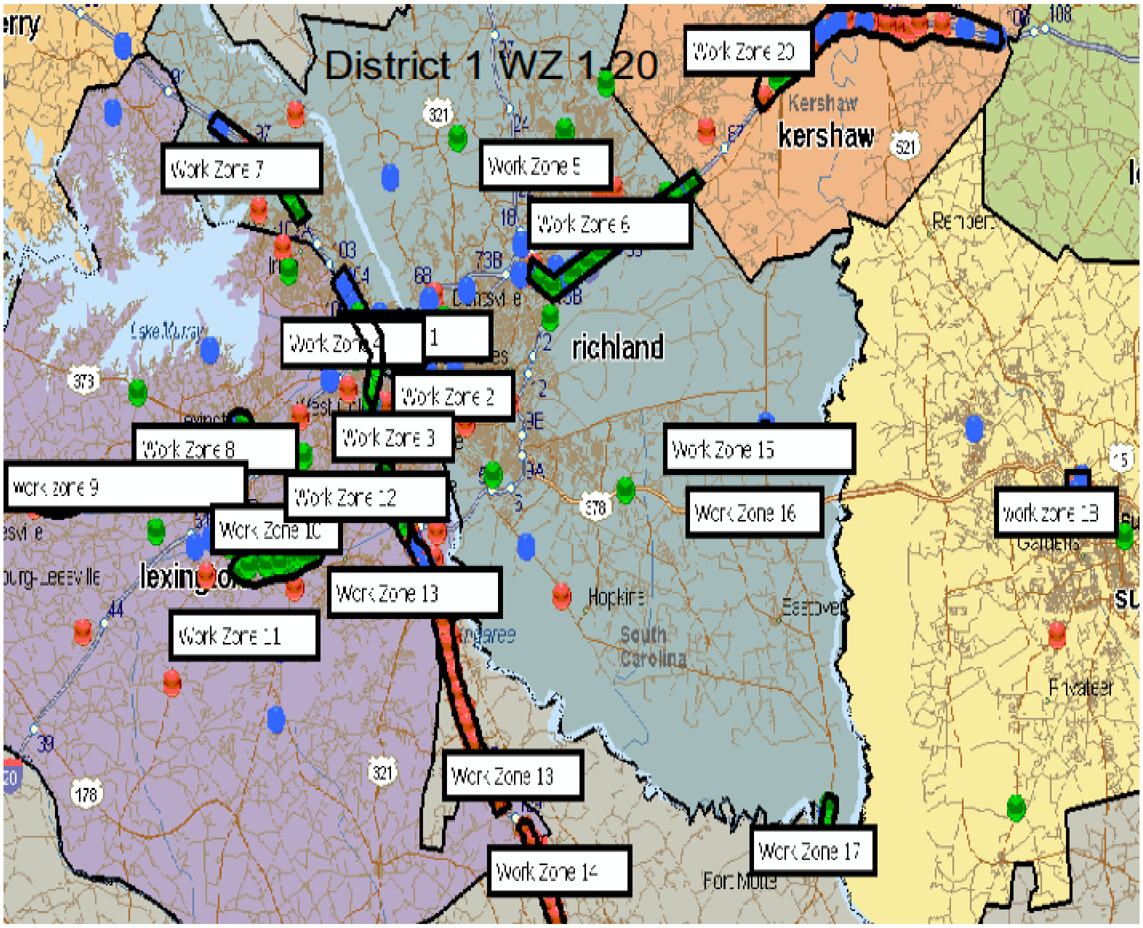


Figure 4-2: District 1 – All Work Zones

4.5 <u>Quality Measures</u>

An investigation of the quality measurements of nighttime paving vs daytime paving (e.g., mat compaction data, ride quality data, pay factors, etc.) was conducted for South Carolina projects. Key information were mined from SCDOT databases to determine the potential quality issues involved with the nighttime paving. The quality variables for this study were selected with input from the Steering Committee and included ride quality and percent within limits (PWL) of in-place pavement density.

4.6 <u>Cost Issues</u>

An investigation was conducted to determine the effect of nighttime paving on the cost of the construction. Bid price data was obtained and mined from SCDOT's databases to compare, if possible, the cost of nighttime construction to daytime. Information from the contractor's survey was also used for this portion of the project.

4.7 Construction Time

The initial intent of this project was to obtain and analyze data on project construction times and possible weather delays of daytime vs. nighttime projects, but once the actual data began to be acquired from SCDOT, the researchers discovered that this type of information was not collected by SCDOT anywhere in their databases.

4.8 Reasonable Detour Method

An investigation of the effectiveness of the "reasonable detour" concept used by other states was conducted through the survey of State DOTs to determine the advantages and disadvantages of the process. Some follow-up discussions were conducted with states that indicated the use of this method on the national survey.

5 Data Analysis and Results

5.1 Results of National Survey of State DOTs

A nationwide survey of DOTs was conducted in order to obtain the state-of-art being used by other state agencies regarding this topic. A survey of various items of importance was submitted to the steering committee for review. After the completion of this step, the survey was sent to different State DOTs by SC DOT officials. The results of the returns from the surveys have been summarized and shown in Appendix E.

The results indicate that in general:

1. Most states indicated that there is not a major difference when comparing the day time paving verses night time paving considering the law enforcement availability for work zones.
2. Most states indicated that there is not a major difference when comparing the day time paving verses night time paving considering the cost of utilizing the law enforcement for work zones.
3. Many states indicated that they do not have enough data to determine the safety issues during day time paving verses night time paving. However, almost half of the states surveyed concluded that the day time paving is safer than night time paving.
4. Majority of the states indicated that the night time paving operation is more expensive than the day time paving. Approximately 25% of the states indicated that they do not track the cost of the day time paving verses night time paving.
5. Almost half of the states responding to the survey indicated that there is not a major issue regarding the staff availability either for the night time paving or the day time paving. The other half of the states indicted that it is much easier to get the staff for the day time paving verses night time paving operations.
6. Majority of the states indicated that the cost of the staff during the night time paving operation is more expensive than the day time paving. Approximately 40% of the states indicated that they do not see a major cost difference regarding the staff for the day time paving verses night time paving.
7. Most states indicated that when comparing the day time verses night time paving, the following three items are considered to be the most important factors: disruption to the traffic, safety of the public, and safety of the workers.
8. The majority of the states indicated that for low volume roads and arterial collector roads they prefer day time paving operations. However, many of them prefer to conduct the paving during night time for the interest systems.
9. Several states indicated that day time paving operations are easier logistically and yield a better final product; however, many concluded that they do not have enough data to determine the effects on paving time on ease of operation.

5.2 Results of Survey of SC Contractors

A statewide survey of asphalt contractors throughout the state was conducted in order to obtain the latest issues, concerns and perceptions of various contractors regarding the night time paving verses day time paving. A survey of various items of importance was submitted to the steering committee for review. After the completion of this step, the survey was sent to South Carolina

Paving Association (SCAPA) for distribution. The results of the returns from the contractors around the state have been summarized and shown in Appendix F.

The findings of the survey of the state contractors are included as follows:

1. All of the contractors indicated that the night time paving costs are higher than the day time paving projects.
2. All of the contractors indicated that the worker's costs for the night time paving are higher than the day time paving projects.
3. Majority of the respondents indicated that the traffic has prevented them for moving equipment around the job site during day time paving projects.
4. Approximately 1/3 of the respondents indicated that in some cases, during the night time paving, workers could not be available for the job. In addition, 1/3 indicated that the agency representative was not available to resolve issues and the other 1/3 concluded that inadequate lighting was a major issues.
5. Over 85% of the contractors indicated that the night time paving projects takes longer to complete.
6. All of the contractors indicated that the night time paving projects are more affected by the weather related issues compared to the day time paving projects.

5.3 SCDOT District 1 Data Analysis

At first glance (Table 5-1 and Figure 5-1), there are significantly more accidents in work zones for night paving projects (652) than in work zones not designated as night paving projects (175). However, if the time of the accident is considered, there are 630 accidents that occurred during daylight hours and 197 accidents that occurred during nighttime hours. This does not provide the whole story as some crashes occur when there are no workers or activity present. It should also be noted that some of the night paving projects allowed for daytime paving during off-peak times.

Table 5-1: Summary of accidents from District 1 with time of day and activity data accounted for.

Case	Bid As Night Paving?	Time of Accident	Active?	Accidents
1	No	Day	No	84
2	Yes	Day	No	244
3	No	Night	No	38
4	Yes	Night	No	72
5	No	Day	Yes	52
6	Yes	Day	Yes	250
7	No	Night	Yes	1
8	Yes	Night	Yes	86

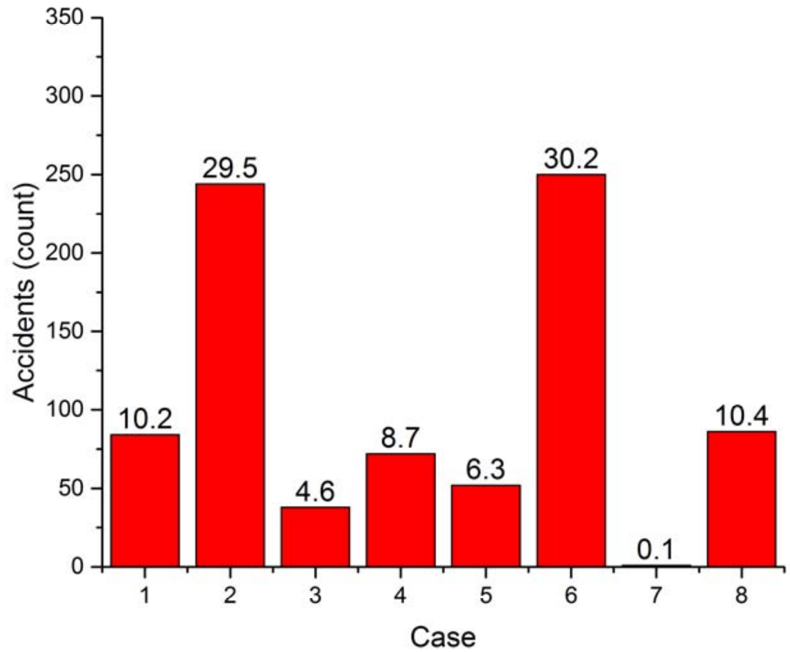


Figure 5-1: Accident counts from all accidents in District 1. The number above each bar is the percentage of total accidents for that particular case.

Interestingly, the number of accidents that occurred in active work zones (389) is roughly half of the total accidents (827). Examination of the accidents that only occurred in active work zones shows that there were 302 accidents in daytime hours and 87 accidents in nighttime hours. Other comparisons can be made but a rigorous statistical analysis is needed to ensure proper comparison.

A Chi-Squared Goodness of Fit (GOF) test can be run on the data collected. The first comparison examines the data as if each case was independent of project type and activity (Table 5-2). Based on the results, and even a cursory glance of the data, it is clear that there are certain cases which occur at statistically higher frequency. The next analysis isolates the work zone activity level to see if an active work zone is more accident prone than an inactive work zone. The results of this analysis (Table 5-3) indicate that the activity level has no statistical influence on the cause of accidents. This is an interesting finding in that it suggests that work zones in District 1 are setup in such a way that they minimize the distractions of the active work zone to drivers. However, there are other possibilities and would need to be explored in further detail to see if this was in fact the case.

Table 5-2: Chi-Square GOF test results for all cases in District 1. The Chi-Square statistic was 583.6 with 7 degrees of freedom and a p-value of less than 0.0001.

Case	Accidents	Expected Accidents	Deviation
1	84	103.38	-18.6%
2	244	103.38	136%
3	38	103.38	-63.2%
4	72	103.38	-30.4%
5	52	103.38	-49.7%
6	250	103.38	141%
7	1	103.38	-99.0%
8	86	103.38	-16.8%

Table 5-3: Chi-Square GOF test results for active daytime and nighttime paving projects in District 1. The Chi-Square statistic was 2.78 with 1 degree of freedom and a p-value of 0.095.

Case	Accidents	Expected Accidents	Deviation
Inactive Work Zone	438	413.5	5.93%
Active Work Zone	389	413.5	-5.93%

Another analysis was conducted to see if the project type (daytime vs. nighttime) was a factor in the frequency of accidents. There is a strong and statistically significant increase in accidents for nighttime projects (Table 5-4). This could be due to how work zones are setup for nighttime paving compared to daytime paving or may simply be an artifact of a larger number of nighttime paving projects being contracted.

Table 5-4: Chi-Square GOF test results for bid daytime and nighttime paving projects in District 1. The Chi-Square statistic was 274.0 with 1 degree of freedom and a p-value less than 0.0001.

Case	Accidents	Expected Accidents	Deviation
Nighttime Bid Project	652	413.5	57.7%
Daytime Bid Project	175	413.5	-57.7%

Up to this point, the degree of injury has not been used in the analysis since it is not a binary value (i.e. “yes” or “no”). However, a logit regression can be performed on the data and the injury information can be a part of the analysis. Furthermore, the regression results in a predictive model based on the data used and may have future predictive capabilities. The general equation of the logit regression is shown in Equation (1) where Y is a dummy variable that represents the outcome, a is the constant term of the model, B is the coefficient matrix of the regression, and x is the independent variable(s). The resulting coefficients of the analysis are shown in Table 5-5. The time coefficient, *B1*, is 1 for night and 0 for day. This coefficient is not indicating the project type but what time of day the accident actually occurred. The active coefficient, *B2*, is 1 for active work zone and 0 for an inactive work zone. Finally, the severity coefficient, *B3*, is on a scale of 0 to 4 based on the codes outlined for Injury Status on TR-310 (Rev. 11/2011).

The model overall fits the data extremely well. However, the time of day of the accident, which is independent of whether the project was a night paving project, appears to be a poor indicator of the potential of an accident and may not have a significant impact. The coefficients and the model can be expanded into a useful form, Equation (2), to allow for the calculation of the probability, *p*, that certain conditions may occur during a nighttime paving operation.

$$Y = a + Bx \tag{1}$$

Table 5-5: Logit regression for District 1 crash data. The regression had a Chi-squared statistic of 35.2 and a p-value of 1.1E-7.

	Coefficient	Std. Error	t-statistic	p-value
a	1.0362	0.125	8.269	1.35E-16
B_1 (Time)	0.1238	0.208	0.595	0.552
B_2 (Active)	0.9117	0.183	4.962	6.98E-7
B_3 (Severity)	-0.3757	0.122	-3.078	0.002

$$p = \frac{1}{1 + e^{-a-Bx}} \tag{2}$$

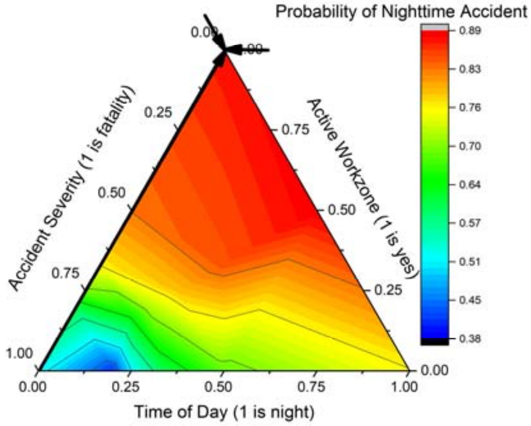
An example is provided for clarity. Suppose the probability that a daytime accident [$B_1 = 0$], in an active work zone [$B_2 = 1$], that results in an incapacitating injury [$B_3 = 3$] is wanted for a bid nighttime construction project. The probability of such an occurrence can be calculated as shown in Equation (3). The model estimates that with the provided conditions, there is a 69% chance the accident would happen in a nighttime paving project and only a 31% chance it would happen during a daytime paving project.

$$p = \frac{1}{1+e^{-a-Bx}} = \frac{1}{1+e^{-1.0362-0.1238(0)-0.9117(1)+0.3757(3)}} = 0.69 \tag{3}$$

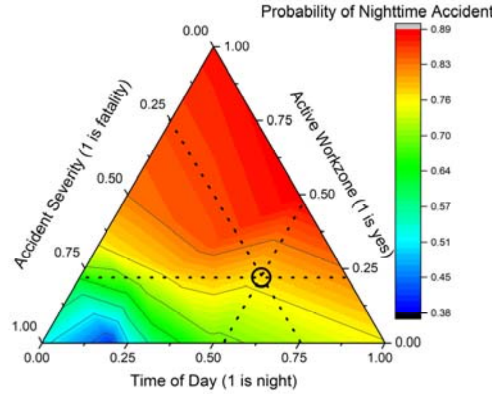
There are 20 different combinations that could be run through the model. A heat map can be generated ((c)

Figure 5-2) from the model to show the critical conditions that are present for nighttime paving project accidents. Note that the heat map normalizes the accident severity from a scale of 0 – 4 to 0 – 1 with 1 indicating a fatality. The data strongly indicates that the majority of nighttime accidents occur in active work zones but have low rates of significant injury. The most severe accidents appear to happen in the daytime but within inactive work zones and with a low probability that the project was bid as a nighttime paving project. This suggests there may be some influence from normal driving trends since there is generally more traffic flow during the day. Further analysis with accident information for each site before and after the work zone was established could provide insight into whether the accidents that occur during the daytime in inactive work zones are more severe due to the work zone presence or is simply the normal trend of accidents for that area.

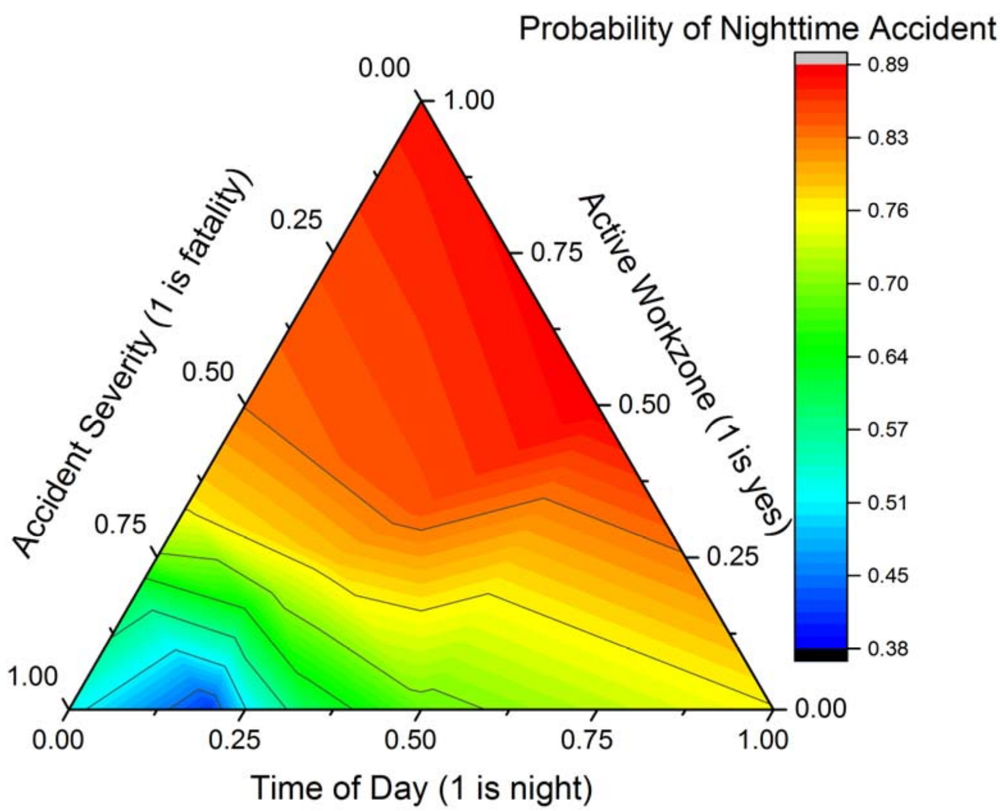
For clarity, two example cases are presented so that the heat map can be appropriately understood. Example one examines a boundary condition. If the probability of an accident, having no injury and in an active work zone during the daytime hours, occurring is desired, the heat map can be read as shown in Figure 5-2(a) and would indicate that scenario has an 89% chance of occurring in a nighttime bid project. A second example considers the case of reading a point of interest off of the heat map. The point of interest is read in an identical manner as a ternary phase diagram, commonly used in the material science field. Parallel lines are drawn from each axis and their values are determined by the scale. The axis tick marks are aligned in the direction that they should be drawn to aid the reader. Reading the point in the second example (Figure 5-2 (b)), there is a 79% chance that a nighttime bid project would have a minor injury, with a near 50/50 chance of the time of the accident being during the day, and an approximately 75% preference that the work zone is inactive.



(a)



(b)



(c)

Figure 5-2: Heat map of District 1 accident data (c) based on the logit regression model. Values are a function of the probability of an accident occurring for a bid nighttime paving project.

Comparing construction costs is extremely difficult due to the many variables at play. Each project was bid with different amounts of materials and it is not accurate to compare the unit price of material at 200 tons and 10,000 tons. Furthermore, with the variety of projects ranging from resurfacing to new construction, it is difficult to find enough data to form a thorough comparison. The most useful material comparison for District 1 appears to be the Base A material. It was present in almost every project, and there is enough data to make a statistical comparison. A Student's t-test was run on the data (Table 5-6) assuming unequal variances, using a Welch correction, since the variance is not known for either data set with any certainty. The results indicate that there is a statistical difference, at a 95% confidence level, between the day and nighttime bid prices with the daytime bid prices being lower (p-value = 0.035).

Table 5-6: Comparison of bid prices for District 1 with respect to Base A material.

Daytime Bid Price [per ton]	Nighttime Bid Price [per ton]
$43.40	$50.00
$43.75	$63.65
$43.00	$82.50
$39.95	$48.00
	$66.00

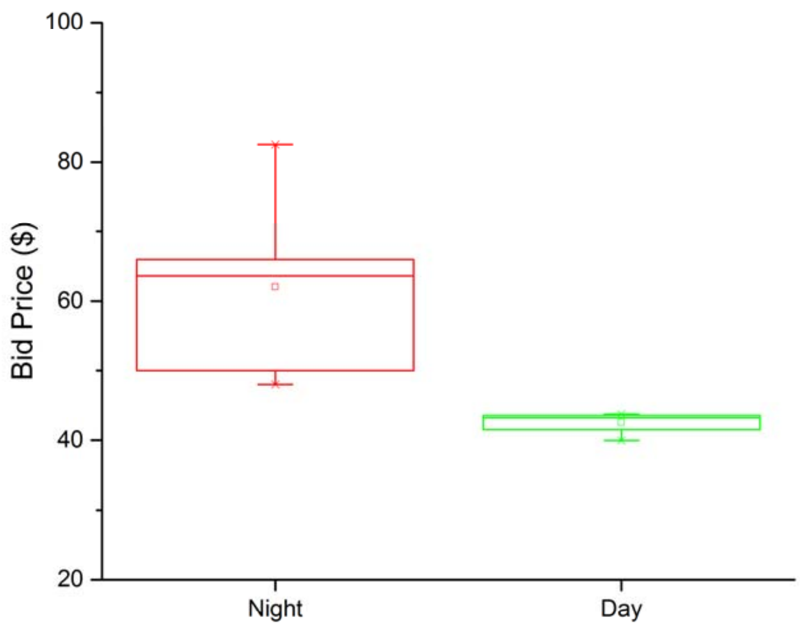


Figure 5-3: Box plot comparing the day and nighttime bid prices for material Base A. The small square point indicates the mean and the large box encompasses 75% of the total data range.

Although the percent within limits (PWL) data for in-place density was available for the projects in District 1, not enough data was available for each different mix type to form any statistically-significant comparisons within District 1. However, the District 1 PWL data for in-place density was included in the statewide analysis in Section 5.10 of this report.

The ride quality acceptance data for various pavement segments constructed in District 1 were also analyzed for the projects that had data available (Figure 5-4). A substantial portion of nighttime projects had bonus pay on ride quality segments, while daytime projects had significantly fewer. However, more daytime projects received 100% pay for the ride quality segments analyzed. With respect to penalty and repaired segments, daytime projects had a higher prevalence than nighttime projects. For District 1, it appears that nighttime projects have an increased prevalence of passing segments with respect to ride quality.

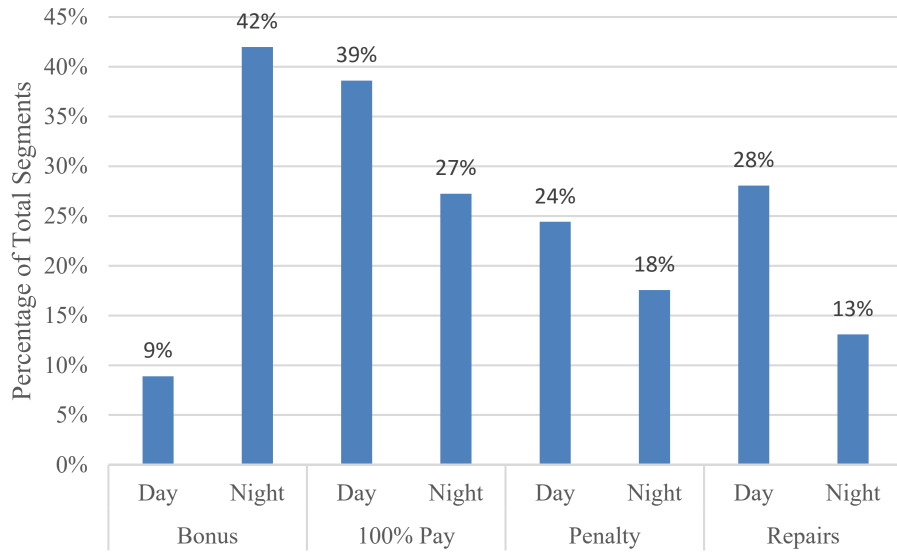


Figure 5-4: Ride quality inspection results for segments in District 1.

5.4 SCDOT District 2 Data Analysis

At first glance (Table 5-7 and Figure 5-5), it appears that there were slightly more accidents in nighttime paving projects (62) than daytime paving projects (41). However, if the time of the accident is considered, there are 75 accidents that occurred during daylight hours and 28 accidents that occurred during nighttime hours. This does not provide the whole story as some crashes occur when there are no workers or activity present. It should also be noted that some of the night paving projects allowed for daytime paving during off-peak times.

Table 5-7: Summary of accidents from District 2 with time of day and activity data accounted for.

Case	Bid As Night Paving?	Time of Accident	Active?	Accidents
1	No	Day	No	7
2	Yes	Day	No	19
3	No	Night	No	4
4	Yes	Night	No	6
5	No	Day	Yes	26
6	Yes	Day	Yes	23
7	No	Night	Yes	4
8	Yes	Night	Yes	14

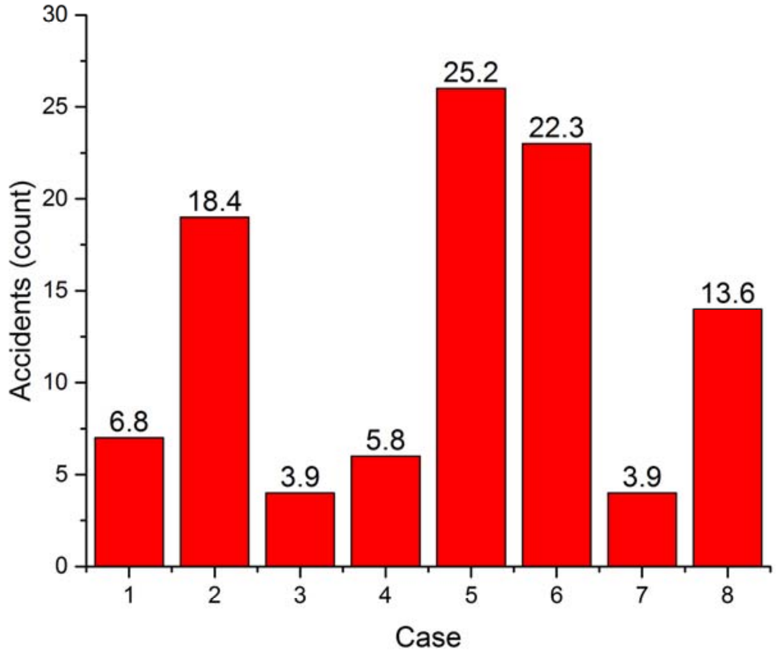


Figure 5-5: Accident counts from all accidents in District 2. The number above each bar is the percentage of total accidents for that particular case.

A Chi-Squared Goodness of Fit (GOF) test can be run on the data collected. It should be noted that the number of total accidents in District 2 is rather low and may skew the statistical analysis. The first comparison examines the data as if each case was independent of project type and activity (Table 5-8). Based on the results, and even a cursory glance of the data, it is clear that there are certain cases which occur at statistically higher frequency.

The next analysis isolates the work zone activity level to see if an active work zone is more accident prone than an inactive work zone. The results of this analysis (Table 5-9) indicate that the activity level has some statistical influence on the cause of accidents. This potentially suggests that the work zone layout in District 2 is not conducive to mitigating accidents. However, the low number of total accidents makes any conclusion tenuous. More information such as traffic flow counts would be needed to assess the accuracy of the conclusion that active work zones in District 2 are inherently more accident prone.

Another analysis was conducted to determine if the project type (daytime vs. nighttime) was a factor in the frequency of accidents. There is a strong and statistically significant increase in accidents for nighttime projects (Table 5-10). This could be due to how work zones are setup for nighttime paving compared to daytime paving or may simply be an artifact of a larger number of nighttime paving projects being contracted.

Table 5-8: Chi-Square GOF test results for all cases in District 2. The Chi-Square statistic was 42.9 with 7 degrees of freedom and a p-value of less than 0.0001.

Case	Accidents	Expected Accidents	Deviation
1	7	12.875	-45.6%
2	19	12.875	47.6%
3	4	12.875	-68.9%
4	6	12.875	-53.4%
5	26	12.875	101%
6	23	12.875	78.6%
7	4	12.875	-68.9%
8	14	12.875	8.7%

Table 5-9: Chi-Square GOF test results for active and inactive daytime and nighttime paving projects in District 2. The Chi-Square statistic was 99.0 with 1 degree of freedom and a p-value of less than 0.0001.

Case	Accidents	Expected Accidents	Deviation
Inactive Work Zone	36	51.5	-30.1%
Active Work Zone	67	51.5	30.1%

Table 5-10: Chi-Square GOF test results for active nighttime and daytime bid paving projects in District 2. The Chi-Square statistic was 99.0 with 1 degree of freedom and a p-value of less than 0.0001.

Case	Accidents	Expected Accidents	Deviation
Nighttime Bid Project	62	51.5	20.4%
Daytime Bid Project	41	51.5	-20.4%

The same logit regression that was used for the District 1 data was applied to the data from District 2. This adds in a factor of the injury severity. The general equation of the logit regression is shown in Equation (1) where *Y* is a dummy variable that represents the outcome, *a* is the constant term of the model, *B* is the coefficient matrix of the regression, and *x* is the independent variable(s). The resulting coefficients of the analysis are shown in Table 5-11. The regression is a poor fit of the data. It is likely that the small number of events is contributing to the fact that a good fit cannot be found. The model is only valid to a confidence of 80%. Nevertheless, a graphical representation of the model is shown in Figure 5-6 for comparison purposes. It appears, unlike in District 1, the most severe accidents occur during the day, in inactive work zones that were bid as a nighttime paving project. This could suggest that the way the work zone is setup for nighttime paving operations is different enough compared to the daytime operations that it causes more severe accidents to occur.

Table 5-11: Logit regression for District 2 crash data. The regression had a Chi-squared statistic of 4.69 and a p-value of 0.196.

	Coefficient	Std. Error	t-statistic	p-value
a	0.5949	0.388	1.535	0.125
B_1 (Time)	0.6555	0.485	1.352	0.176
B_2 (Active)	-0.6497	0.444	-1.462	0.144
B_3 (Severity)	0.2286	0.304	0.753	0.451

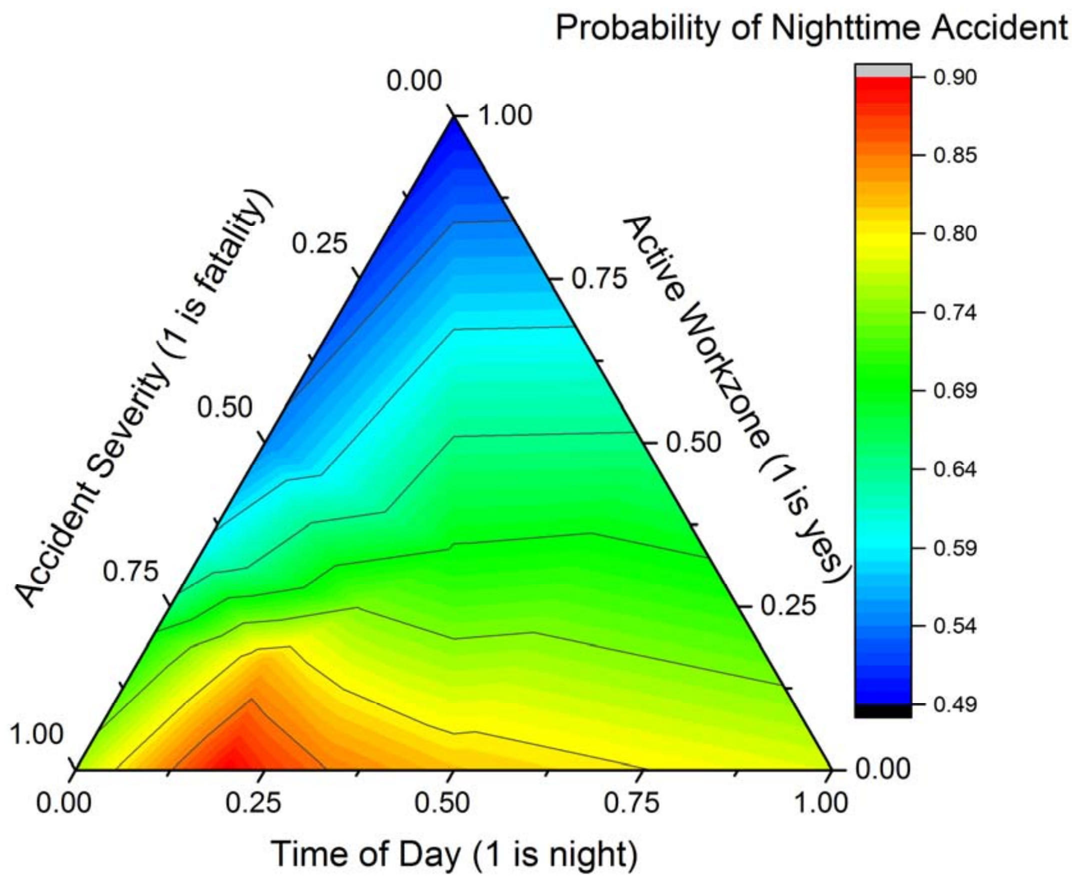


Figure 5-6: Heat map of District 2 accident data based on the logit regression model. Values are a function of the probability of an accident occurring for a bid nighttime paving project.

Although material bid prices and percent within limits (PWL) data for in-place density were available for the projects in District 2, not enough data was available for each different mix type to form any statistically-significant comparisons within District 2. However, the District 2 bid price data and PWL data for in-place density were included in the statewide analysis in Section 5.10 of this report.

The ride quality acceptance data for various pavement segments constructed in District 2 were also analyzed for the projects that had data available (Figure 5-7). Almost all of the ride quality segments of nighttime projects had bonus pay while daytime projects had significantly fewer. However, more daytime projects received 100% pay for the ride quality segments analyzed. With respect to penalty and repaired segments, both nighttime and daytime projects had negligible segments failing requirements for ride quality.

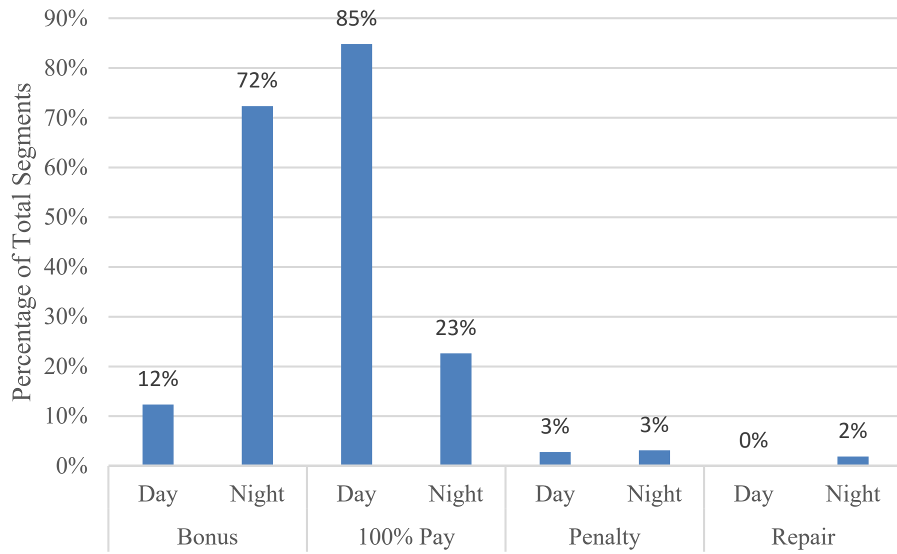


Figure 5-7: Ride quality inspection results for segments in District 2.

5.5 SCDOT District 3 Data Analysis

At first glance (Table 5-12 and Figure 5-8), it appears that there were slightly more accidents in daytime paving projects (215) than nighttime paving projects (166). If the time of the accident is taken into account, there are 284 accidents that occurred during daylight hours and 97 accidents that occurred during nighttime hours. This does not provide the whole story as some crashes occur when there are no workers or activity present. It should also be noted that some of the night paving projects allowed for daytime paving during off-peak times.

A Chi-Squared Goodness of Fit (GOF) test can be run on the data collected. The first comparison examines the data as if each case was independent of project type and activity (Table 5-13). Based on the results, and even a cursory glance of the data, it is clear that there are certain cases which occur at statistically higher frequency.

The next analysis isolates the work zone activity level to see if an active work zone is more accident prone than an inactive work zone. The results of this analysis (Table 5-14) indicate that the activity level has no statistical influence on the cause of accidents. This is a somewhat surprising finding. Generally, it would be expected that an active work zone would have a higher rate of accidents due to distractions of the work crews on drivers. It would be interesting to compare the accident data before and after the work zone was set up to see if there was any statistical change in the accident rate. It is possible that either the layout of work zones in District 3 are not ideal, or the specific construction projects during this time had complicated work zone requirements.

Table 5-12: Summary of accidents from District 3 with time of day and activity data accounted for.

Case	Bid As Night Paving?	Time of Accident	Active?	Accidents
1	No	Day	No	77
2	Yes	Day	No	66
3	No	Night	No	21
4	Yes	Night	No	18
5	No	Day	Yes	65
6	Yes	Day	Yes	76
7	No	Night	Yes	52
8	Yes	Night	Yes	6

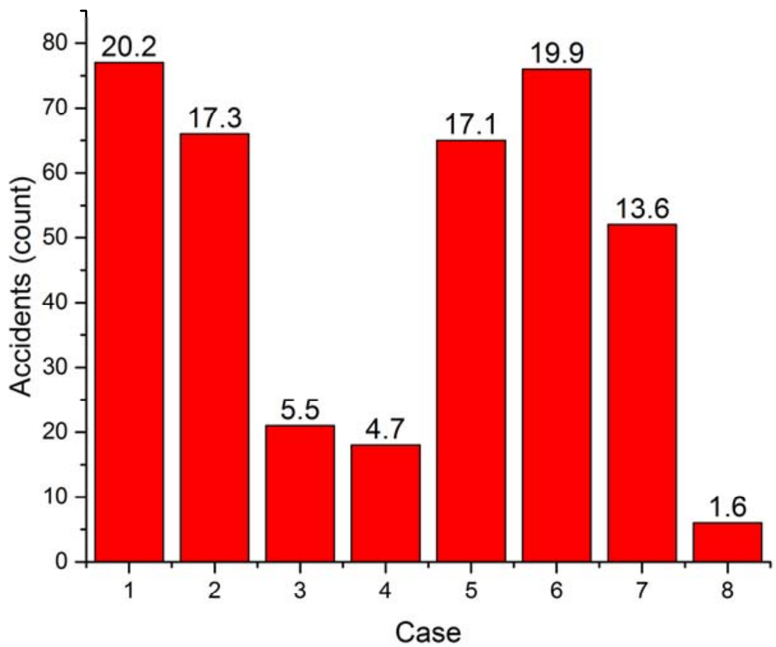


Figure 5-8: Accident counts from all accidents in District 3. The number above each bar is the percentage of total accidents for that particular case.

The bid type (daytime vs. nighttime) was also analyzed to see if it was a significant factor in accident frequency (Table 5-15). The daytime projects had a statistically higher chance of an accident. However, this does not take into account when a given accident occurred. Coupled with the analysis in Table 5-14, it appears that the procedures and layout for work zones in District 3 should be examined closely and the specific projects used in this analysis should be examined. These surprising results may be an artifact of a complicated work zone setup or very high traffic levels.

Table 5-13: Chi-Square GOF test results for all cases in District 3. The Chi-Square statistic was 118.5 with 7 degrees of freedom and a p-value of less than 0.0001.

Case	Accidents	Expected Accidents	Deviation
1	77	47.625	61.7%
2	66	47.625	38.6%
3	21	47.625	-55.9%
4	18	47.625	-62.2%
5	65	47.625	36.5%
6	76	47.625	59.6%
7	52	47.625	9.2%
8	6	47.625	-87.4%

Table 5-14: Chi-Square GOF test results for active and inactive daytime and nighttime paving projects in District 3. The Chi-Square statistic was 0.76 with 1 degree of freedom and a p-value of 0.38.

Case	Accidents	Expected Accidents	Deviation
Inactive Work Zone	182	190.5	-4.5%
Active Work Zone	199	190.5	4.5%

Table 5-15: Chi-Square GOF test results for nighttime and daytime bid projects in District 3. The Chi-Square statistic was 6.0 with 1 degree of freedom and a p-value of 0.01.

Case	Accidents	Expected Accidents	Deviation
Nighttime Bid Project	166	190.5	-12.9%
Daytime Bid Project	215	190.5	12.9%

The same logit regression that was used for the previous districts was applied to the data from District 3. This adds in a factor of the injury severity. The general equation of the logit regression is shown in Equation (1) where *Y* is a dummy variable that represents the outcome, *a* is the constant term of the model, *B* is the coefficient matrix of the regression, and *x* is the independent variable(s). The resulting coefficients are presented in Table 5-16. The graphical representation of the regression is shown in Figure 5-9. Similar to District 2, it appears that the most severe accidents occur during the daytime but for nighttime projects. This is another indication that the work zone layout may be an issue for nighttime paving operations. It could also be a function of travel levels but this factor cannot be analyzed with the available data.

Table 5-16: Logit regression for District 3 crash data. The regression had a Chi-squared statistic of 21.2 and a p-value of 9.5E-5.

	Coefficient	Std. Error	t-statistic	p-value
a	0.0212	0.164	0.130	0.897
B_1 (Time)	-1.1240	0.266	-4.224	<0.001
B_2 (Active)	-0.1364	0.213	-0.640	0.522
B_3 (Severity)	0.1926	0.173	1.115	0.265

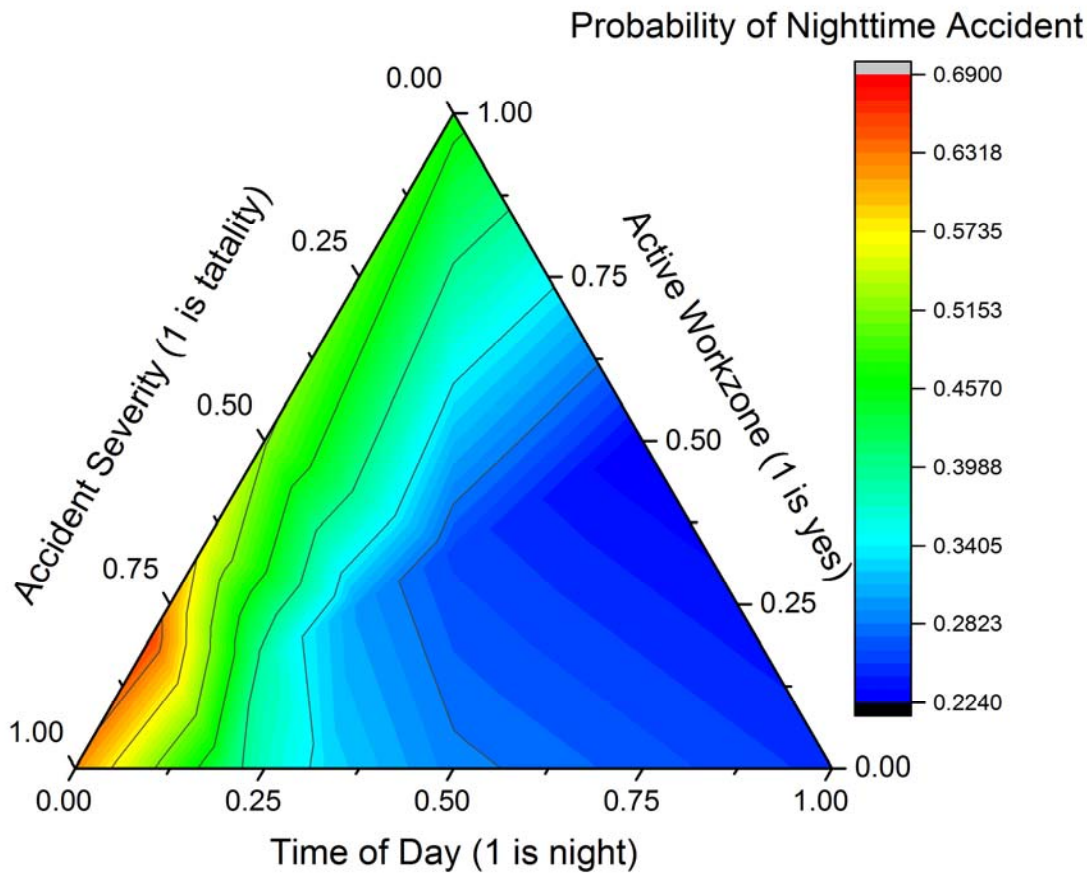


Figure 5-9: Heat map of District 3 accident data based on the logit regression model. Values are a function of the probability of an accident occurring for a bid nighttime paving project.

Although material bid prices and percent within limits (PWL) data for in-place density were available for the projects in District 3, not enough data was available for each different mix type to form any statistically-significant comparisons within District 3. However, the District 3 bid price data and PWL data for in-place density were included in the statewide analysis in Section 5.10 of this report.

The ride quality acceptance data for District 3 is generally similar to that of District 2 (Figure 5-10). The nighttime projects had a higher frequency of bonus pay while the daytime projects had a higher number of projects receiving 100% pay. While the daytime projects did have more penalty and repair segments, compared to the overall percentage they were minimal and on the same order of magnitude as the nighttime projects.

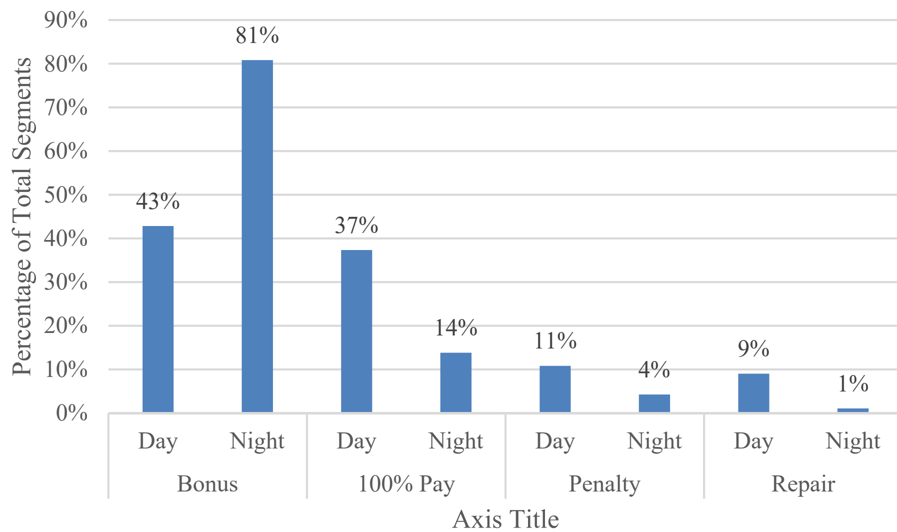


Figure 5-10: Ride quality inspection results for segments in District 3.

5.6 SCDOT District 4 Data Analysis

At first glance (Table 5-17 and Figure 5-11), it appears that there were significantly more accidents in nighttime paving projects (109) than daytime paving projects (27). If the time of the accident is taken into account, there are 112 accidents that occurred during daylight hours and 24 accidents that occurred during nighttime hours. It should also be noted that some of the night paving projects allowed for daytime paving during off-peak times.

The severe skewedness of the data makes any type of rigorous statistical analysis questionable. For this district's dataset to be properly analyzed, the traffic volume and total number of work zones, including those where no accidents occurred, during the analysis period must be known. The apparent conclusion is that nighttime paving projects have more accidents compared to the daytime, but this cannot be supported or refuted with sound statistical methodology.

Table 5-17: Summary of accidents from District 4 with time of day and activity data accounted for.

Case	Bid As Night Paving?	Time of Accident	Active?	Accidents
1	No	Day	No	7
2	Yes	Day	No	46
3	No	Night	No	3
4	Yes	Night	No	13
5	No	Day	Yes	10
6	Yes	Day	Yes	49
7	No	Night	Yes	7
8	Yes	Night	Yes	1

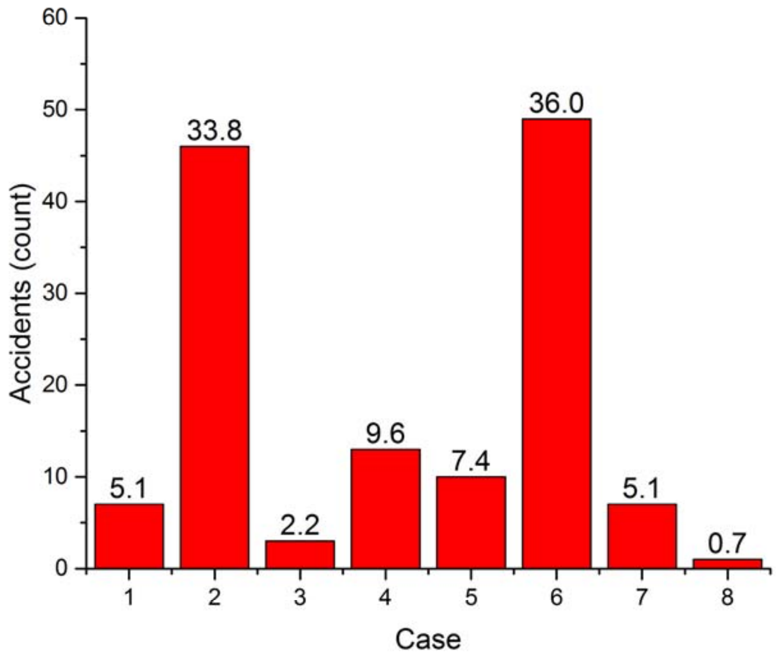


Figure 5-11: Accident counts from all accidents in District 4. The number above each bar is the percentage of total accidents for that particular case.

For the sake of completeness, a logit regression, similar to the ones performed for the previous districts, was performed on the dataset for District 4. It should be noted that there was no information regarding the injury severity of each accident so that term was removed from the regression (Table 5-18). The probability table that can be built from the regression is shown in Table 5-19. The analysis matches the conclusions that can be drawn from the raw data in that most of the accidents are occurring in the daytime for work zones that are bid as nighttime paving projects. Similar to other districts, this suggests that either the higher volume of traffic during daytime hours is skewing the data or the method of establishing the layout of the work zone for nighttime projects is not ideal.

Table 5-18: Logit regression for District 4 crash data. The regression had a Chi-squared statistic of 12.2 and a p-value of 0.002.

	Coefficient	Std. Error	t-statistic	p-value
a	2.3424	0.432	5.420	<0.001
B_1 (Time)	-1.6549	0.530	-3.122	0.002
B_2 (Active)	-1.0137	0.487	-2.081	0.037

Table 5-19: Results from logit regression of District 4 data. Percentages are probability that the condition will occur within a nighttime bid paving project.

	Inactive Work Zone	Active Work Zone
Daytime Accident	91%	79%
Nighttime Accident	67%	42%

Although material bid prices and percent within limits (PWL) data for in-place density were available for the projects in District 4, not enough data was available for each different mix type to form any statistically-significant comparisons within District 4. However, the District 4 bid price data and PWL data for in-place density were included in the statewide analysis in Section 5.10 of this report.

Keeping with trend from the first three districts, the data from District 4 shows that nighttime projects have more ride quality bonus segments while daytime projects have more 100% pay segments (Figure 5-12). The ride quality penalty and repair segments for both daytime and nighttime projects are similar and of similar magnitudes to Districts 2 and 3. This consistent prevalence of nighttime projects receiving significantly more ride quality bonus segments may either be a result of construction techniques or there may be an inherent bias with ride quality acceptance measurements for nighttime projects.

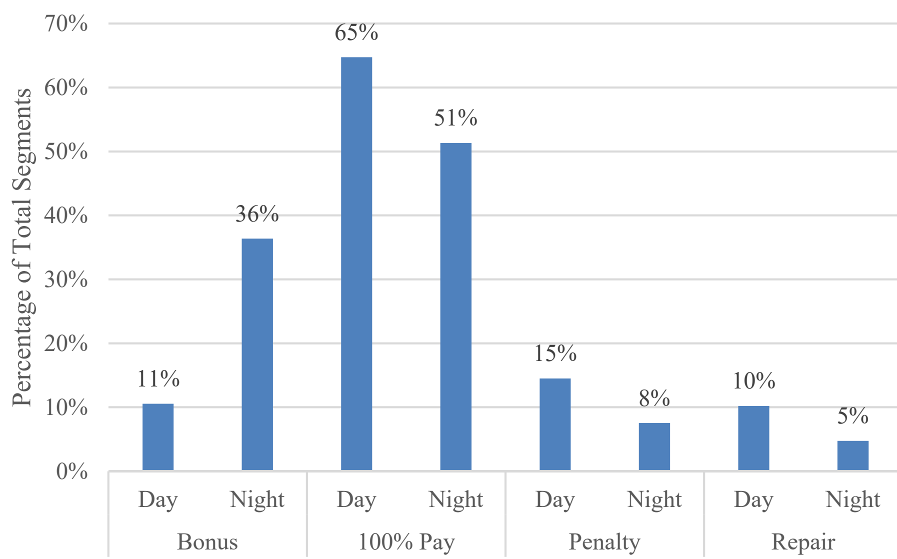


Figure 5-12: Ride quality inspection results for segments in District 4.

5.7 SCDOT District 5 Data Analysis

At first glance (Table 5-20 and Figure 5-13) it appears that there were fewer accidents in daytime paving projects (34) than nighttime paving projects (58). If the time of the accident is taken into account, there are 65 accidents that occurred during daylight hours and 27 accidents that occurred during nighttime hours. This does not provide the whole story as some crashes occur when there are no workers or activity present. It should also be noted that some of the night paving projects allowed for daytime paving during off-peak times.

Table 5-20: Summary of accidents from District 5 with time of day and activity data accounted for.

Case	Bid As Night Paving?	Time of Accident	Active?	Accidents
1	No	Day	No	12
2	Yes	Day	No	22
3	No	Night	No	1
4	Yes	Night	No	15
5	No	Day	Yes	11
6	Yes	Day	Yes	20
7	No	Night	Yes	10
8	Yes	Night	Yes	1

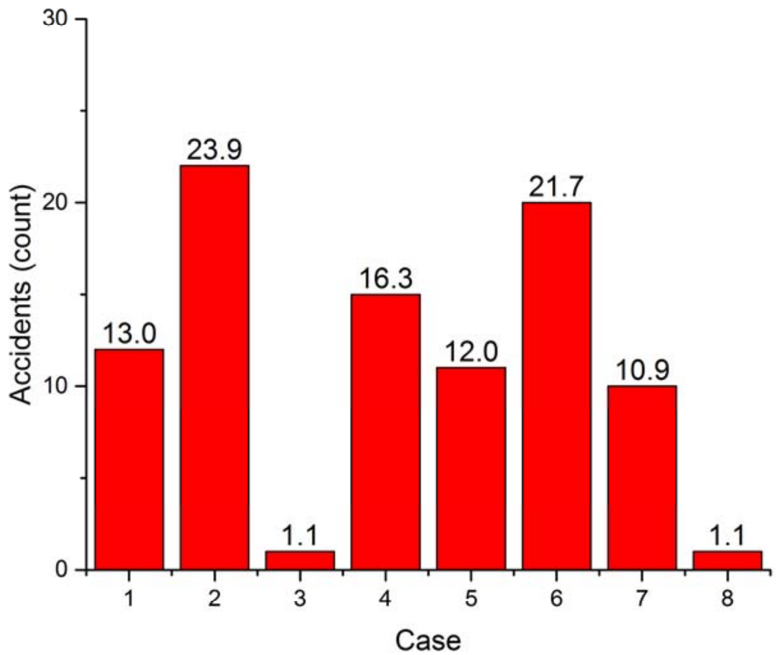


Figure 5-13: Accident counts from all accidents in District 5. The number above each bar is the percentage of total accidents for that particular case.

A Chi-Squared Goodness of Fit (GOF) test can be run on the data collected. The first comparison examines the data as if each case was independent of project type and activity (Table 5-21). Based on the results, and even a cursory glance of the data, it is clear that there are certain cases which occur at statistically higher frequency. The next analysis isolates the work zone activity level to see if an active work zone is more accident-prone than an inactive work zone. The results of this analysis (Table 5-22) indicate that the activity level had no statistical influence on the cause of accidents. This is a somewhat surprising finding. Generally, it would be expected that an active work zone would have a higher rate of accidents due to distractions of the work crews on drivers. It would be interesting to compare the accident data before and after the work zone was set up to see if there was any statistical change in the accident rate. It is possible that the layout of work zones in District 5 is not ideal or the specific construction projects during this time had complicated work zone requirements.

The bid type (daytime vs. nighttime) was also analyzed to determine if it was a significant factor in accident frequency (Table 5-23). The nighttime projects had a statistically higher chance of an accident. Coupled with the analysis in Table 5-22, it appears that nighttime paving projects cause more accidents even if the work zone is inactive. This could be a result of traffic levels, which are unknown, or the procedures used to establish the work zone for nighttime paving operations.

Table 5-21: Chi-Square GOF test results for all cases in District 5. The Chi-Square statistic was 36.4 with 7 degrees of freedom and a p-value of less than 0.0001.

Case	Accidents	Expected Accidents	Deviation
1	12	11.5	4.6%
2	22	11.5	91.3%
3	1	11.5	-91.3%
4	15	11.5	30.4%
5	11	11.5	-4.4%
6	20	11.5	73.9%
7	10	11.5	-13.0%
8	1	11.5	-91.3%

Table 5-22: Chi-Square GOF test results for active and inactive daytime and nighttime paving projects in District 5. The Chi-Square statistic was 0.54 with 1 degree of freedom and a p-value of 0.46.

Case	Accidents	Expected Accidents	Deviation
Inactive Work Zone	50	46	8.7%
Active Work Zone	42	46	-8.7%

Table 5-23: Chi-Square GOF test results for nighttime and daytime bid projects in District 5. The Chi-Square statistic was 5.8 with 1 degree of freedom and a p-value of 0.02.

Case	Accidents	Expected Accidents	Deviation
Nighttime Bid Project	58	46	26.1%
Daytime Bid Project	34	46	-26.1%

The same logit regression that was used for the previous districts was applied to the data from District 5. This adds in a factor of the injury severity. The general equation of the logit regression is shown in Equation (1) where Y is a dummy variable that represents the outcome, a is the constant term of the model, B is the coefficient matrix of the regression, and x is the independent variable(s). The resulting coefficients are presented in Table 5-24. The graphical representation of the regression is shown in Figure 5-14. Similar to previous districts, it appears that the most severe accidents occur during the daytime hours but for nighttime bid projects. This is another indication that the work zone layout may be an issue for nighttime paving operations. It could also be a function of travel levels but this factor cannot be analyzed with the provided data.

Table 5-24: Logit regression for District 5 crash data. The regression had a Chi-squared statistic of 8.3 and a p-value of 0.04.

	Coefficient	Std. Error	t-statistic	p-value
a	1.016	0.377	2.693	0.007
B_1 (Time)	-0.529	0.518	-1.022	0.307
B_2 (Active)	-1.022	0.455	-2.245	0.025
B_3 (Severity)	0.472	0.341	1.383	0.167

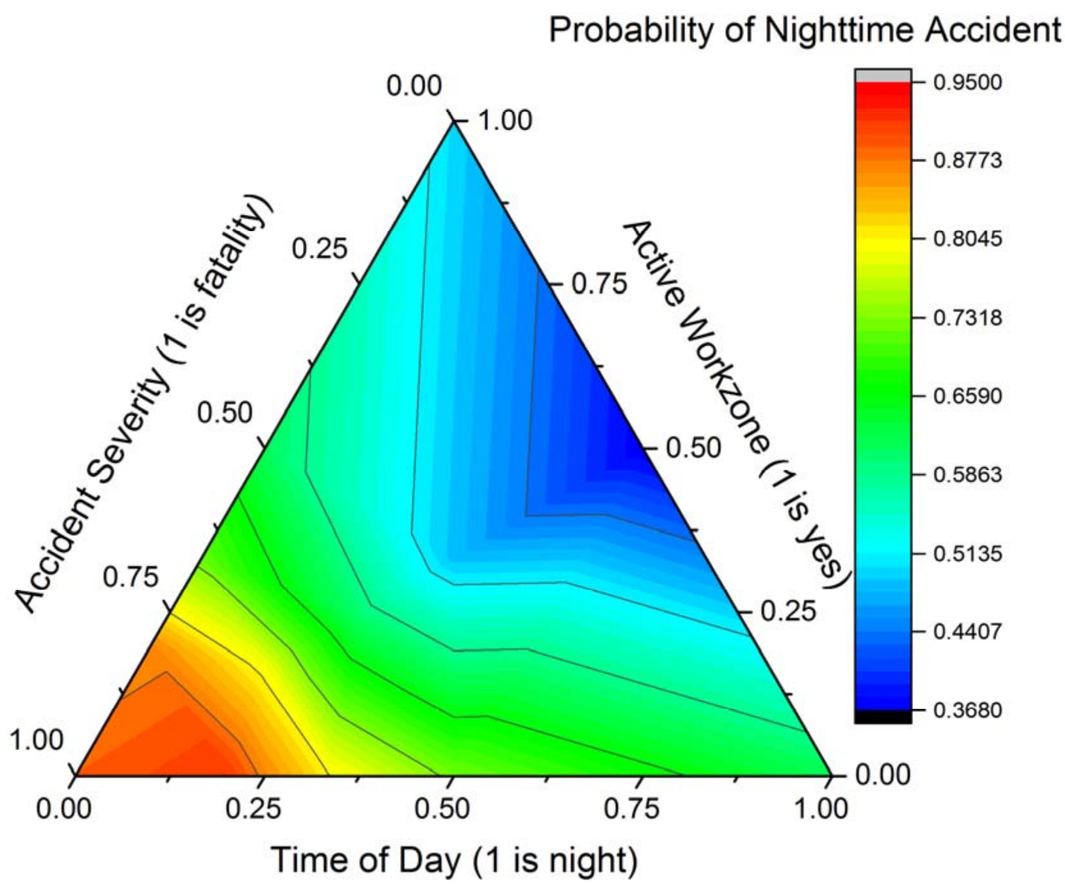


Figure 5-14: Heat map of District 5 accident data based on the logit regression model. Values are a function of the probability of an accident occurring for a bid nighttime paving project.

Although material bid prices and percent within limits (PWL) data for in-place density were available for the projects in District 5, not enough data was available for each different mix type to form any statistically-significant comparisons within District 5. However, the District 5 bid price data and PWL data for in-place density were included in the statewide analysis in Section 5.10 of this report.

District 5 ride quality acceptance data contains slightly different trends than the previously analyzed districts (Figure 5-15). The daytime projects had a much higher prevalence of ride quality bonus segments, while both daytime and nighttime projects had a high overall percentage of ride quality segments receiving 100% pay. Similar to the previous districts, the ride quality penalty and repair segments for both daytime and nighttime bid projects were approximately equal.

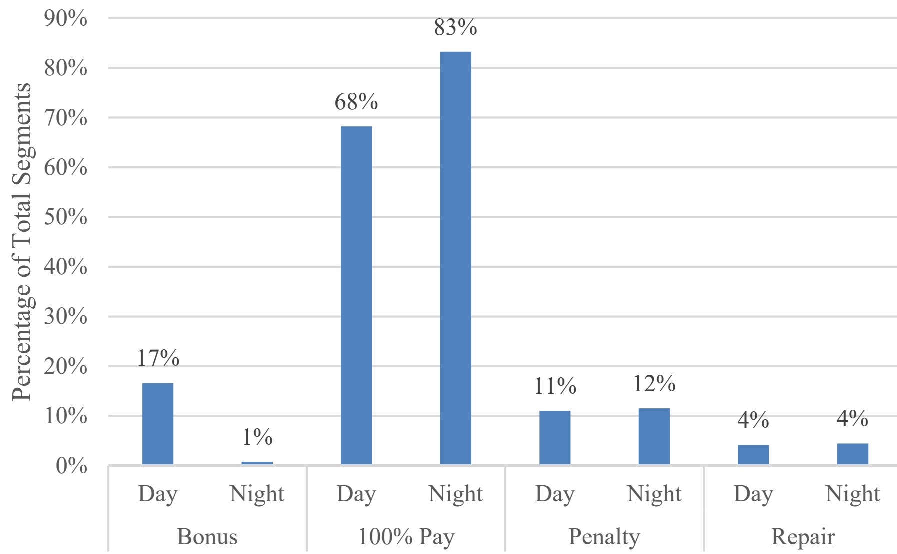


Figure 5-15: Ride quality inspection results for segments in District 5.

5.8 SCDOT District 6 Data Analysis

At first glance (Table 5-25 and Figure 5-16), there are significantly more accidents in work zones that were bid as night paving projects (579) than in work zones not designated as night paving (22). However, if the time of the accident is considered, there are 433 accidents that occurred during daylight hours and 168 accidents that occurred during nighttime hours. This does not provide the whole story as some crashes occur when there are no workers or activity present. It should also be noted that some of the night paving projects allowed for daytime paving during off-peak times. There were several projects in this district that were listed as day and nighttime projects. Due to the binary nature of the statistical analysis, these work zones could not be analyzed.

Table 5-25: Summary of accidents from District 6 with time of day and activity data accounted for.

Case	Bid As Night Paving?	Time of Accident	Active?	Accidents
1	No	Day	No	4
2	Yes	Day	No	309
3	No	Night	No	6
4	Yes	Night	No	141
5	No	Day	Yes	9
6	Yes	Day	Yes	111
7	No	Night	Yes	3
8	Yes	Night	Yes	18

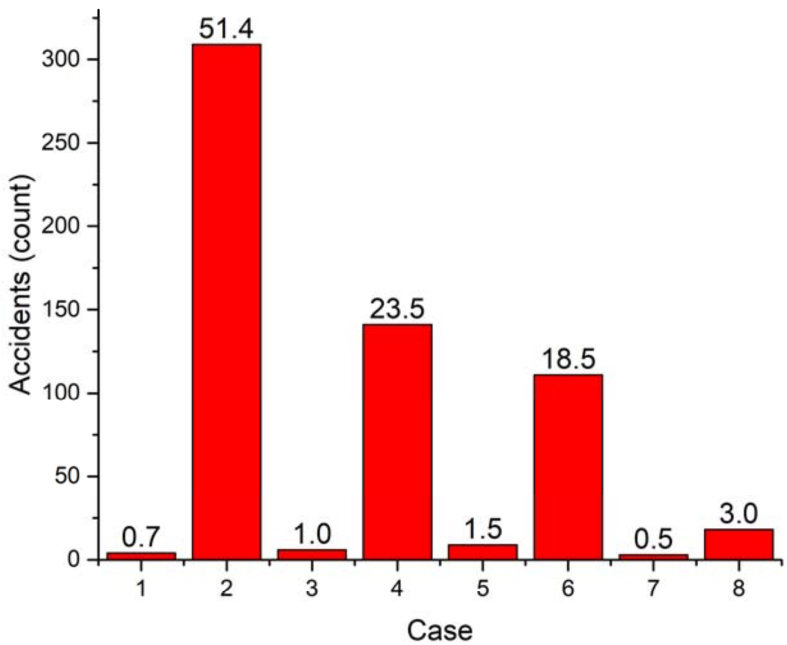


Figure 5-16: Accident counts from all accidents in District 6. The number above each bar is the percentage of total accidents for that particular case.

Interestingly, the number of accidents that occurred in active work zones (141) is about a fourth of the total accidents (601). Examination of the accidents that only occurred in active work zones shows that the majority (120) occurred during the daytime hours and only 21 accidents in nighttime hours. Other comparisons can be made but a rigorous statistical analysis is needed to ensure proper comparison.

A Chi-Squared Goodness of Fit (GOF) test can be run on the data collected. The first comparison examines the data as if each case was independent of project type and activity (Table 5-26). Based on the results, and even a cursory glance of the data, it is clear that there are certain cases which occur at statistically higher frequency. The next analysis isolates the work zone activity level to determine if an active work zone is more accident prone than an inactive work zone. The results of this analysis (Table 5-27) indicate that the activity level has a statistical influence on the cause of accidents and, unexpectedly, inactive work zones were more prone to accidents. This suggests that the work zone procedures work while workers are present but something significant happens when inactive (e.g. removal of signs) or perhaps less caution from drivers with knowledge that the work zone is inactive. However, there are other possibilities and would need to be explored in further detail to see if this was in fact the case.

Table 5-26: Chi-Square GOF test results for all cases in District 6. The Chi-Square statistic was 1104 with 7 degrees of freedom and a p-value of less than 0.0001.

Case	Accidents	Expected Accidents	Deviation
1	4	71.125	-94.4%
2	309	71.125	334%
3	6	71.125	-91.6%
4	141	71.125	98.2%
5	9	71.125	-87.4%
6	111	71.125	56.1%
7	3	71.125	-95.6%
8	18	71.125	-74.7%

Table 5-27: Chi-Square GOF test results for active daytime and nighttime paving projects in District 6. The Chi-Square statistic was 169.3 with 1 degree of freedom and a p-value of less than 0.0001.

Case	Accidents	Expected Accidents	Deviation
Inactive Work Zone	460	300.5	53.1%
Active Work Zone	141	300.5	-53.1%

Another analysis was conducted to determine if the project bid type (nighttime vs. daytime) was a factor. There is a strong and statistically significant increase in accidents for nighttime projects (Table 5-28). This could be due to how work zones are set up for nighttime paving compared to daytime paving or may simply be an artifact of a larger number of nighttime paving projects being contracted.

Table 5-28: Chi-Square GOF test results for bid daytime and nighttime paving projects in District 6. The Chi-Square statistic was 516.2 with 1 degree of freedom and a p-value less than 0.0001.

Case	Accidents	Expected Accidents	Deviation
Nighttime Bid Project	579	300.5	92.7%
Daytime Bid Project	22	300.5	-92.7%

The same logit regression that was used for the previous districts was applied to the data from District 6. This adds in a factor of the injury severity. The general equation of the logit regression is shown in Equation (1) where *Y* is a dummy variable that represents the outcome, *a* is the constant term of the model, *B* is the coefficient matrix of the regression, and *x* is the independent variable(s). The resulting coefficients are presented in Table 5-29. The graphical representation of the regression is shown in Figure 5-14. Similar to previous districts, it appears that the most severe accidents occur during the daytime hours but for nighttime bid projects. This is another indication that the work zone layout may be an issue for nighttime paving operations. It could also be a function of travel levels but this factor cannot be analyzed with the provided data.

The model overall fits the data extremely well. However, the injury severity, which is independent of whether the project was a night paving project, appears to be a poor indicator of the potential of an accident and may not have a significant impact on the overall model.

Table 5-29: Logit regression for District 6 crash data. The regression had a Chi-squared statistic of 15.2 and a p-value of 0.00164.

	Coefficient	Std. Error	t-statistic	p-value
a	4.1764	0.415	10.069	7.6E-24
B_1 (Time)	-1.0562	0.478	-2.209	0.027
B_2 (Active)	-1.7151	0.467	-3.669	2.4E-4
B_3 (Severity)	0.2381	0.273	0.872	0.383

There are 20 different combinations that could be run through the model. A heat map can be generated (Figure 5-17) from the model to show the critical conditions that are present for nighttime paving project accidents. Note that the heat map normalizes the accident severity from a scale of 0 – 4 to 0 – 1 with 1 indicating a fatality. The most severe accidents, with high probability of a fatality, appear to happen in the daytime but within inactive work zones and with a high probability that the project was bid as a nighttime paving project. This suggests there may be some influence from normal driving trends since there is generally more traffic flow during the day. Further analysis with accident information for each site before and after the work zone was established could provide insight into whether the accidents that occur during the daytime in inactive work zones are more severe due to the work zone presence or is simply the normal trend of accidents for that area. It should be noted that due to the extremely high percentage of nighttime bid projects, the logit regression predicts nearly every accident possibility would occur at a nighttime bid jobsite with at least 80% probability.

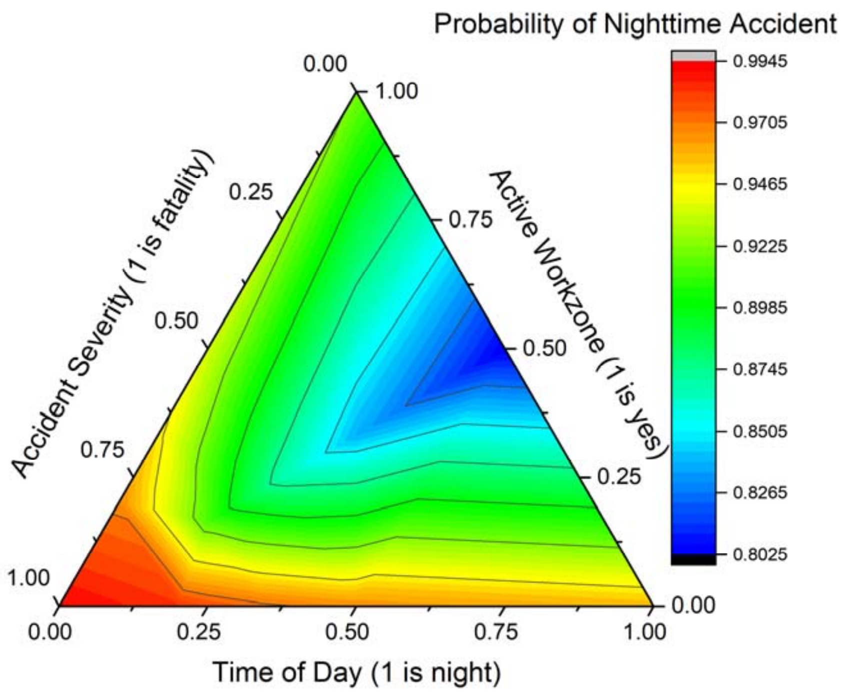


Figure 5-17: Heat map of District 6 accident data based on the logit regression model. Values are a function of the probability of an accident occurring for a bid nighttime paving project.

Although material bid prices and percent within limits (PWL) data for in-place density were available for the projects in District 6, not enough data was available for each different mix type to form any statistically-significant comparisons within District 6. However, the District 6 bid price data and PWL data for in-place density were included in the statewide analysis in Section 5.10 of this report.

5.9 SCDOT District 7 Data Analysis

At first glance (Table 5-30 and Figure 5-18), it appears that there were significantly fewer accidents in daytime paving projects (38) than nighttime paving projects (151). However, if the time of the accident is taken into account, there are 147 accidents that occurred during daylight hours and 42 accidents that occurred during nighttime hours. This does not provide the whole story as some crashes occur when there are no workers or activity present. It should also be noted that some of the night paving projects allowed for daytime paving during off-peak times.

A Chi-Squared Goodness of Fit (GOF) test can be run on the data collected. The first comparison examines the data as if each case was independent of project type and activity (Table 5-31). Based on the results, and even a cursory glance of the data, it is clear that there are certain cases which occur at statistically higher frequency. The next analysis isolates the work zone activity level to see if an active work zone is more accident prone than an inactive work zone. The results of this analysis (Table 5-32) indicate that the activity level has a statistical influence on the cause of accidents and that inactive work zones, as a whole, have more accidents. Generally, it would be expected that an active work zone would have a higher rate of accidents due to distractions of the work crews on drivers. It would be interesting to compare the accident data before and after the work zone was set up to see if there was any statistical change in the accident rate. It is possible that the layout of work zones in District 7 are not ideal or the specific construction projects during this time had complicated work zone requirements.

Table 5-30: Summary of accidents from District 7 with time of day and activity data accounted for.

Case	Bid As Night Paving?	Time of Accident	Active?	Accidents
1	No	Day	No	13
2	Yes	Day	No	71
3	No	Night	No	0
4	Yes	Night	No	26
5	No	Day	Yes	24
6	Yes	Day	Yes	39
7	No	Night	Yes	1
8	Yes	Night	Yes	15

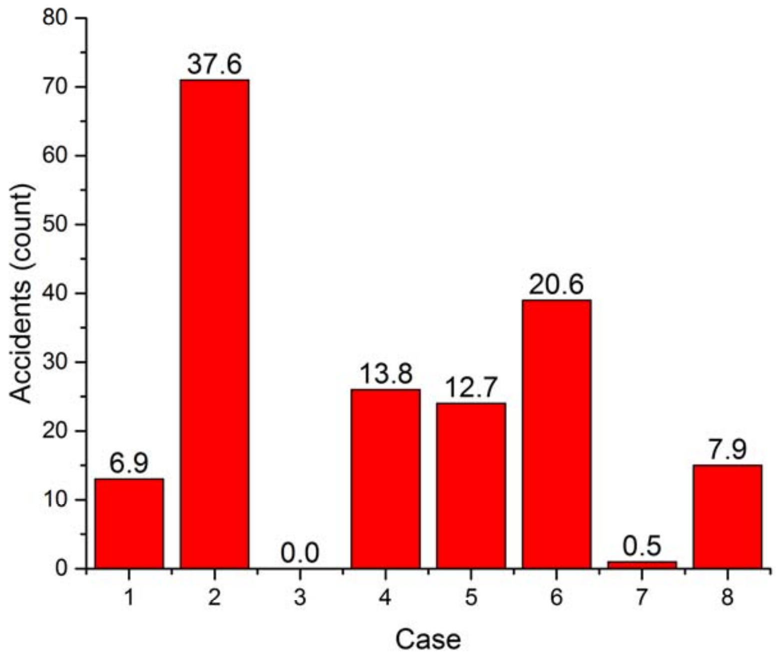


Figure 5-18: Accident counts from all accidents in District 7. The number above each bar is the percentage of total accidents for that particular case.

The bid type (daytime vs. nighttime) was also analyzed to see if it was a significant factor in accident frequency (Table 5-33). The nighttime projects had a statistically higher chance of an accident. Coupled with the analysis in Table 5-32, it appears that nighttime paving projects cause more accidents even if the work zone is inactive. This could be a result of traffic levels, which are unknown, or the procedures used to establish the work zone for nighttime paving operations.

Table 5-31: Chi-Square GOF test results for all cases in District 7. The Chi-Square statistic was 158 with 7 degrees of freedom and a p-value of less than 0.0001.

Case	Accidents	Expected Accidents	Deviation
1	13	23.625	-45.0%
2	71	23.625	200.5%
3	0	23.625	-100%
4	26	23.625	10.0%
5	24	23.625	1.6%
6	39	23.625	65.0%
7	1	23.625	-95.8%
8	15	23.625	-36.5%

Table 5-32: Chi-Square GOF test results for active and inactive daytime and nighttime paving projects in District 7. The Chi-Square statistic was 4.8 with 1 degree of freedom and a p-value of 0.03.

Case	Accidents	Expected Accidents	Deviation
Inactive Work Zone	110	94.5	16.4%
Active Work Zone	79	94.5	-16.4%

Table 5-33: Chi-Square GOF test results for nighttime and daytime bid projects in District 7. The Chi-Square statistic was 66.4 with 1 degree of freedom and a p-value less than 0.0001.

Case	Accidents	Expected Accidents	Deviation
Nighttime Bid Project	151	94.5	59.8%
Daytime Bid Project	38	94.5	-59.8%

The same logit regression that was used for the previous districts was applied to the data from District 7. This adds in a factor of the injury severity. The general equation of the logit regression is shown in Equation (1) where Y is a dummy variable that represents the outcome, a is the constant term of the model, B is the coefficient matrix of the regression, and x is the independent variable(s). The resulting coefficients are presented in Table 5-34. The graphical representation of the regression is shown in Figure 5-19. Unlike previous districts, it appears that the most severe accidents occur during the nighttime hours but for nighttime bid projects. This is another indication that the work zone layout may be an issue for nighttime paving operations. It could also be a function of travel levels but this factor cannot be analyzed with the provided data.

Table 5-34: Logit regression for District 7 crash data. The regression had a Chi-squared statistic of 26.4 and a p-value less than 0.0001.

	Coefficient	Std. Error	t-statistic	p-value
a	1.822	0.320	5.700	<0.001
B_1 (Time)	2.789	1.050	2.657	0.007
B_2 (Active)	-1.273	0.395	-3.222	0.001
B_3 (Severity)	-0.288	0.264	-1.092	0.275

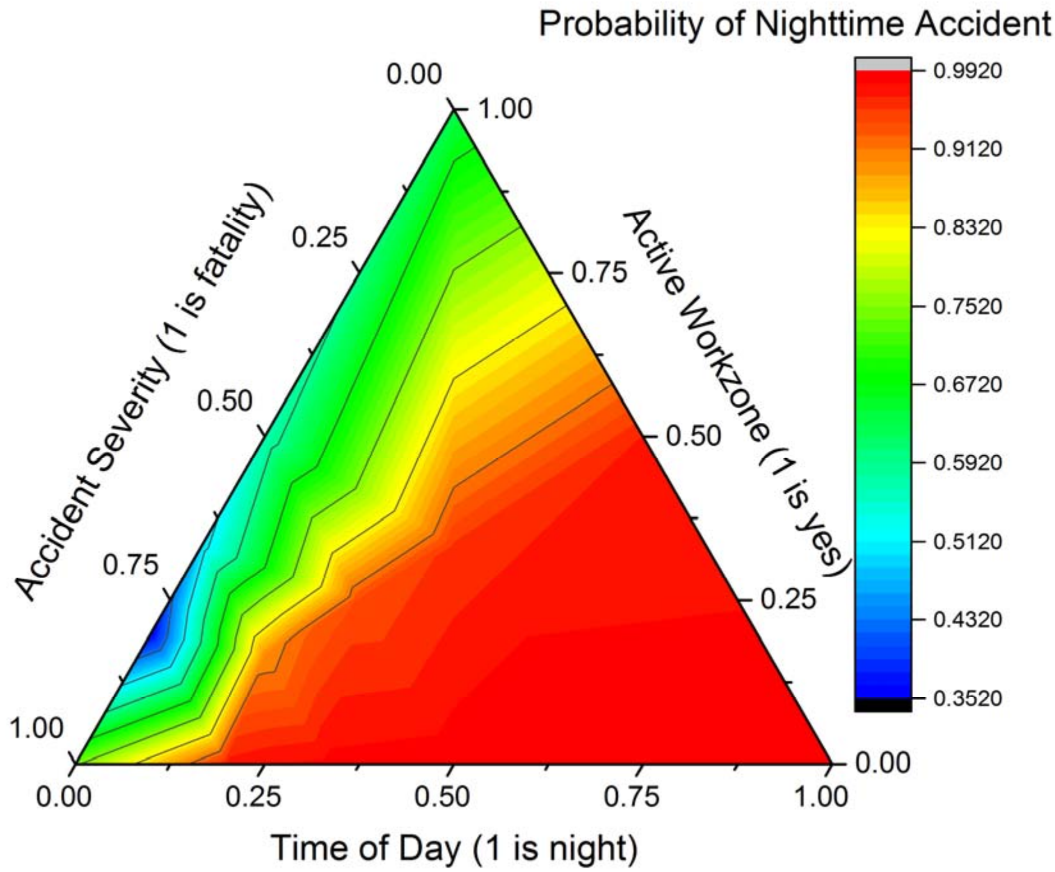


Figure 5-19: Heat map of District 7 accident data based on the logit regression model. Values are a function of the probability of an accident occurring for a bid nighttime paving project.

Although material bid prices and percent within limits (PWL) data for in-place density were available for the projects in District 7, not enough data was available for each different mix type to form any statistically-significant comparisons within District 7. However, the District 7 bid price data and PWL data for in-place density were included in the statewide analysis in Section 5.10 of this report.

District 7 is somewhat unusual in that both daytime and nighttime projects had nearly all ride quality segments receiving 100% pay (Figure 5-20). Daytime projects did have a few ride quality segments that received a bonus, while nighttime projects had no ride quality segments receiving a bonus. As with all the previous districts, the penalty and repair ride quality segments were minimal and comparable between daytime and nighttime projects.

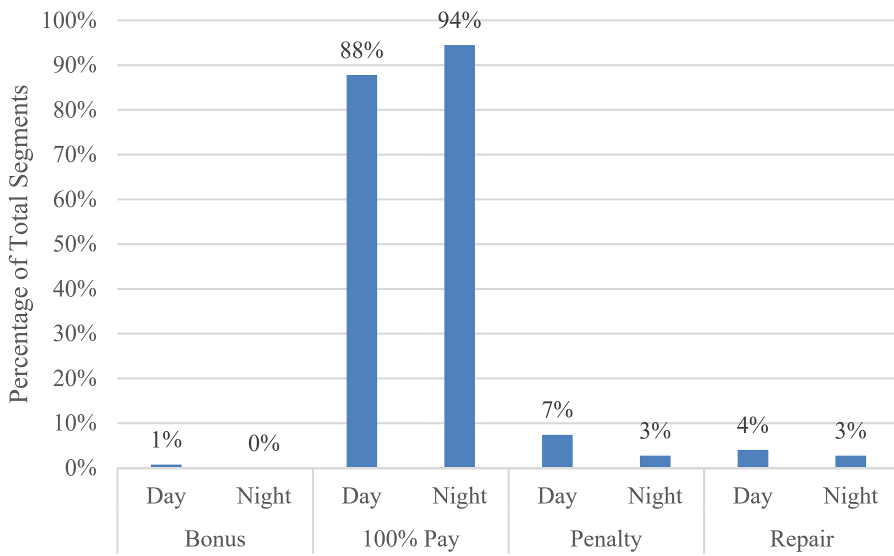


Figure 5-20: Ride quality results for segments in District 7.

5.10 <u>SCDOT All Districts Combined Data Analysis</u>

5.10.1 All Districts Combined – Traffic Accident Analysis

The data from each district was combined, and a single analysis was performed over the entire dataset. Since the decision to promote nighttime or daytime paving operations will be made at the state level, it makes sense to determine the impact of the different types of paving operations without the influence of regional factors. A total of 1728 work zone accidents were analyzed and broken down into the cases that were used for the district level analysis (Table 5-35 and Figure 5-21).

An overwhelming amount of accidents occurred on projects bid as nighttime paving (1,198) compared to daytime bid projects (530). While it is difficult to make a solid conclusion, due to the absence of traffic data, it appears that nighttime paving operations do cause significantly more accidents.

A Chi-Square GOF analysis was run on the data, similar to how it was run individually for each district (Table 5-36). The analysis clearly shows that the different cases are statistically different from one another. Further analysis directly comparing daytime and nighttime projects shows a statistically higher accident count for projects bid as nighttime paving (Table 5-37).

Table 5-35: Summary of accidents from the entire state with time of day and activity data accounted for.

Case	Bid As Night Paving?	Time of Accident	Active?	Accidents
1	No	Day	No	204
2	Yes	Day	No	777
3	No	Night	No	73
4	Yes	Night	No	291
5	No	Day	Yes	197
6	Yes	Day	Yes	568
7	No	Night	Yes	78
8	Yes	Night	Yes	141

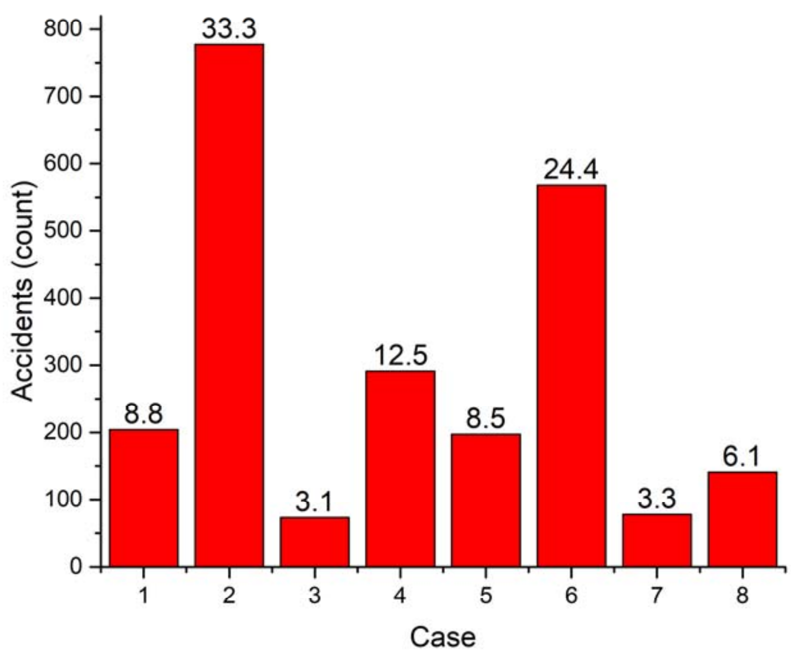


Figure 5-21: Accident counts from all accidents in within the state. The number above each bar is the percentage of total accidents for that particular case.

Table 5-36: Chi-Square GOF test results for all cases in the state. The Chi-Square statistic was 1527 with 7 degrees of freedom and a p-value of less than 0.0001.

Case	Accidents	Expected Accidents	Deviation
1	204	291.125	-29.9%
2	777	291.125	166%
3	73	291.125	-74.9%
4	291	291.125	-0.04%
5	197	291.125	-32.3%
6	568	291.125	95.1%
7	78	291.125	-73.2%
8	141	291.125	-51.6%

Table 5-37: Chi-Square GOF test results for nighttime and daytime bid projects in the state. The Chi-Square statistic was 644 with 1 degree of freedom and a p-value less than 0.0001.

Case	Accidents	Expected Accidents	Deviation
Nighttime Bid Project	1777	1164.5	52.6%
Daytime Bid Project	552	1164.5	-52.6%

Finally, a logit regression was performed on the entire dataset with exception of the missing injury severity data from District 4. The injury severity data was included in the analysis to further quantify the difference between projects bid as nighttime paving or daytime paving. Unlike the regression analysis at the district level, the state level regression is an extremely poor fit to the data (Table 5-38).

This is somewhat surprising given the consistency between districts. When plotted, the data only has a range of probability between 62% and 69% (Figure 5-22). This near constant probability indicates that regardless of the time of day of the accident, activity within the work zone itself, or severity of the injury, there is approximately a 65% chance that any given accident would be at work zone that was bid as a nighttime paving operation.

Table 5-38: Logit regression for entire state crash data with exception of Districts 4. The regression had a Chi-squared statistic of 1.44 and a p-value 0.697.

	Coefficient	Std. Error	t-statistic	p-value
a	0.821	0.084	9.758	<0.001
B_1 (Time)	-0.122	0.125	-0.980	0.327
B_2 (Active)	-0.009	0.108	-0.083	0.934
B_3 (Severity)	-0.044	0.079	-0.564	0.573

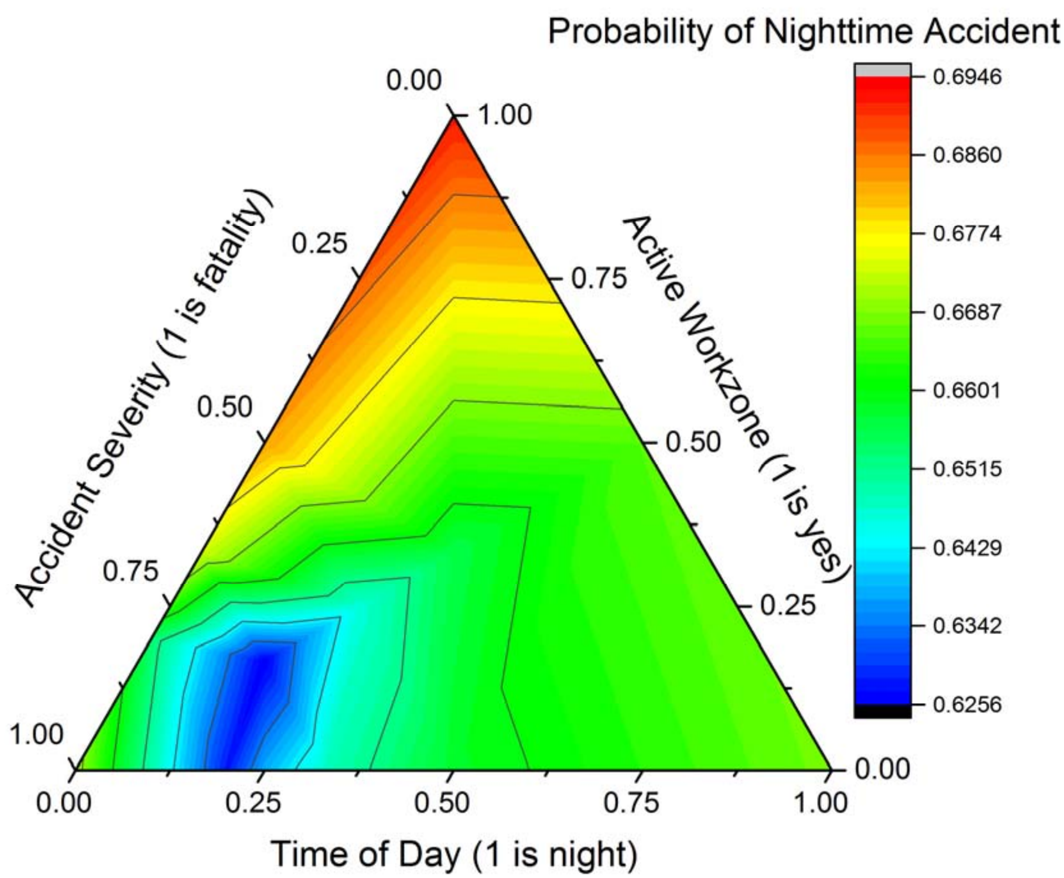


Figure 5-22: Heat map of accident data for the entire state with exception of District 4. The map is based on the logit regression model and values are a function of the probability of an accident occurring for a bid nighttime paving project.

Overall, it can reasonably be concluded, absent of traffic data, that nighttime paving operations cause statistically higher accident rates at various points throughout the day and night and with various injury severity. A much more thorough analysis could be conducted if traffic flow data for each accident location was provided. Each accident could then be weighted against traffic flow. However, that analysis is outside the scope of this project.

5.10.2 All Districts Combined – Bid Price Analysis

Originally, the intent was to analyze the data at the district level and then at the state level. However, some districts were dominated by a few projects, and there was insufficient data to conduct a proper statistical analysis. Thus, the bid price analysis was done at the state level but not at the individual district level.

The bid price analysis examines the effects of nighttime and daytime bid project prices for the six most common material types used in the work zones analyzed (Table 5-39 and Figure 5-23). In general, there appears to be little difference in the bid price between nighttime and daytime construction projects, although the average bid prices for nighttime paving projects were higher for every material type other than OGFC. The higher average bid price for OGFC on daytime projects could be caused by the fact that most projects that utilize OGFC are bid as nighttime paving projects. However, the relatively large standard deviation for most of the bid prices makes any rigorous statistical comparison impossible.

Table 5-39: Statewide bid price data for six most common materials used.

Type	Bid Type	Average Price [$]	Std. Dev. [$]	Total Tonnage
Base A	Day	42.67	5.34	140,377
	Night	56.75	14.62	96,683
Intermediate B	Day	$46.40	$10.25	106688
	Night	$96.04	$9.25	5701
OGFC	Day	$65.00	$9.90	13630
	Night	$52.18	$11.59	96059
Surface A	Day	$45.38	$6.87	10995
	Night	$48.07	$8.24	483842
Surface B	Day	$44.39	$6.47	484469
	Night	$47.26	$5.33	299282
Surface C	Day	$46.04	$10.37	104771
	Night	$52.49	$19.60	87521

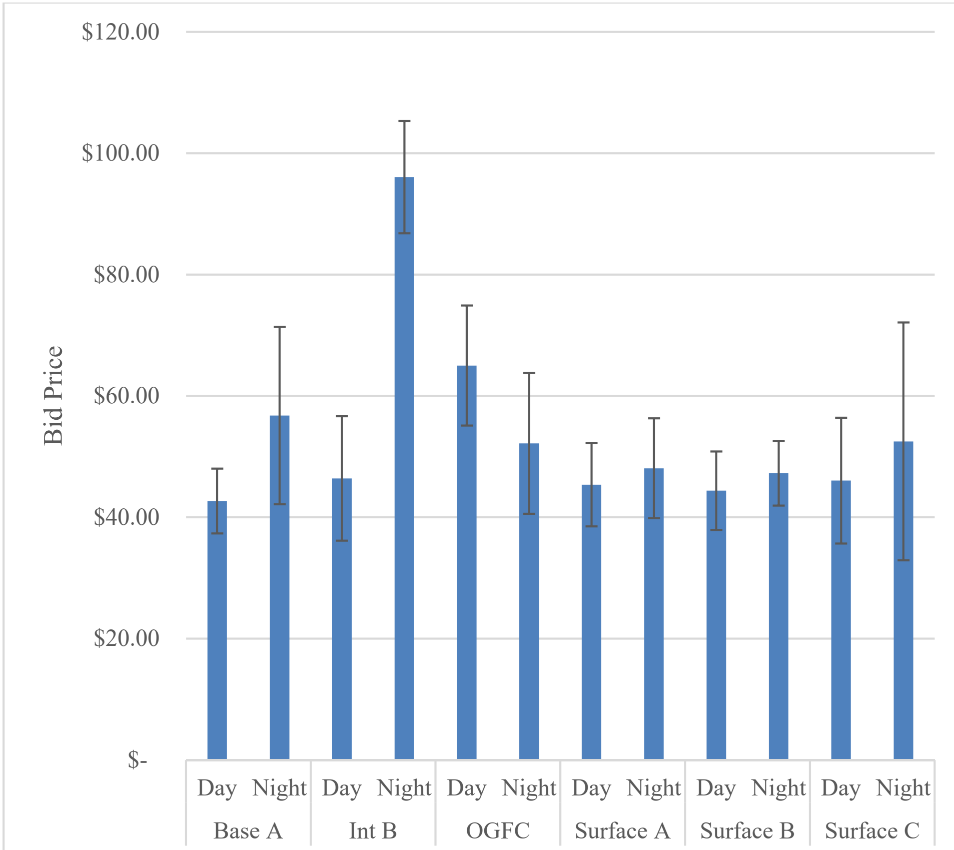


Figure 5-23: Statewide bid price data for six most common materials. Error bars represent the standard deviation.

5.10.3 All Districts Combined – In-Place Density Analysis

As with bid price, originally, the intent was to analyze the in-place density data at the district level and then at the state level. However, some districts were dominated by a few projects, and there was insufficient data to conduct a proper statistical analysis. Thus, the in-place density analysis was done at the state level but not at the individual district level.

This analysis examined the effects of the project type (nighttime vs. daytime paving) on the in-place pavement density for each material (Table 5-40 and Figure 5-24). In-place pavement density is an important factor of pavement life and performance. For this analysis, the percent within limits (PWL) data for in-place density was utilized. Statistically speaking, the PWL data does not provide much information as to a comparison between nighttime and daytime paving projects. Generally, the average PWL for in-place density for daytime projects is higher than the average PWL for nighttime projects, which could indicate that daytime paving operations lead to higher quality pavements. However, this conclusion is only general in nature and not statistically significant.

One interesting part of this analysis is that in nearly every case, the standard deviation of daytime in-place density PWL values was less than the standard deviation of nighttime paving projects. This suggests that even though, statistically speaking, no comparison can be made of the averages, the fact that the standard deviations are lower for daytime projects indicates a more consistent construction procedure is taking place during daytime paving operations, which could lead to higher quality pavements.

A final analysis examined a straight comparison between daytime and nighttime in-place density PWL values regardless of material type (Figure 5-25). For this analysis, all materials were combined in the calculation. Statistically speaking, there was no significant difference between nighttime and daytime projects. However, the average in-place density PWL of daytime projects (99.16%±2.31%) was higher than that of nighttime projects (97.76%±3.36%). This suggests that there might be some bias towards daytime paving projects having higher in-place densities than nighttime paving projects if more data was available.

Table 5-40: Statewide in-place density PWL data for six most common materials.

Type	Bid Type	Average PWL [%]	Std. Dev. [%]	Total Tonnage
Base A	Day	99.62	1.46	140,377
	Night	97.72	2.75	96,683
Intermediate B	Day	100.25	2.31	106688
	Night	96.04	8.78	5701
OGFC	Day	97.42	0.16	13630
	Night	98.90	2.00	96059
Surface A	Day	97.06	3.21	10995
	Night	97.11	4.05	483842
Surface B	Day	99.46	2.39	484469
	Night	97.89	3.46	299282
Surface C	Day	100.20	1.10	104771
	Night	99.76	0.56	87521

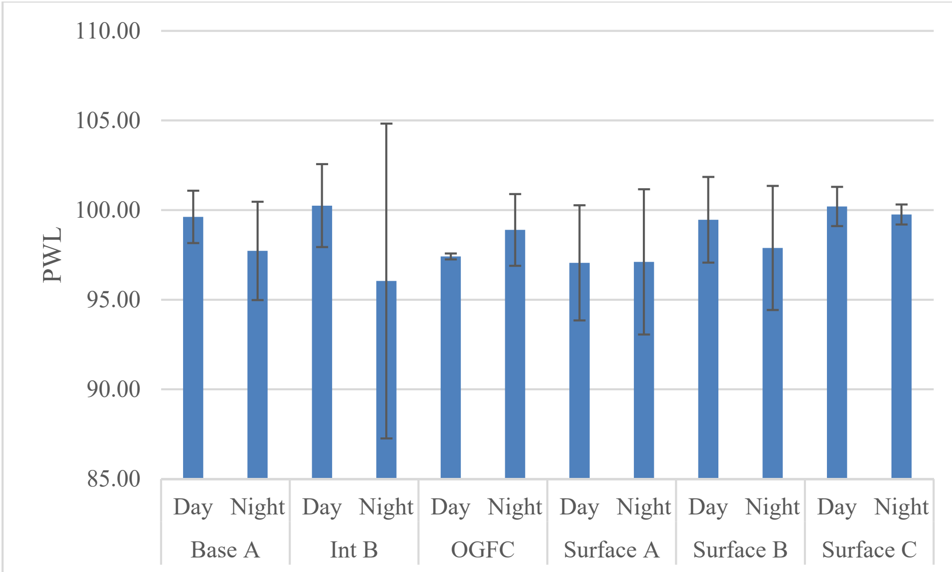


Figure 5-24: Statewide in-place density PWL data for six most common materials. Error bars represent the standard deviation.

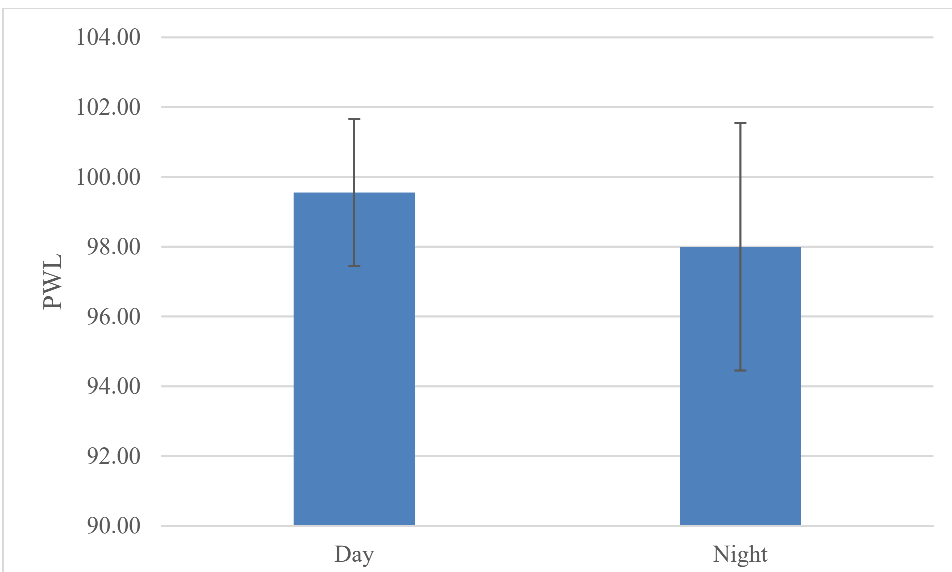


Figure 5-25: Statewide in-place density PWL data for all materials combined. Error bars represent the standard deviation.

5.10.4 All Districts Combined – Ride Quality Analysis

Using the ride quality data from each district, an analysis was conducted statewide to see if any trends are present (Figure 5-26). Nighttime projects had significantly more ride quality bonus segments on a statewide basis, while daytime projects had a significantly higher number of ride quality segments receiving 100% pay. Similar to the district level analysis, the penalty and repair ride quality segment differences between daytime and nighttime projects was not substantial.

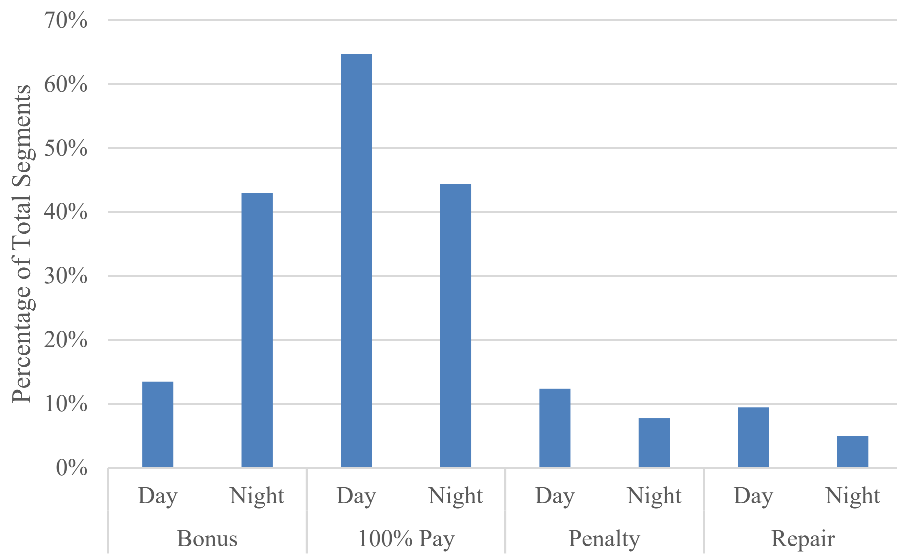


Figure 5-26: Ride quality inspection results for segments in the state.

5.11 Reasonable Detour Analysis

The PI contacted and interviewed several states (GA, TN, AL, and FL) regarding their detour applications. In general, these states considered detours into two categories:

1. the diversion of an existing road or
2. roads that parallel the permanent pavement.

When using an existing road, all states indicated that, based on the engineer's judgement, the existing road may need:

1. structural upgrading before using it as a detour or
2. rehabilitation once the detour is closed.

In addition, the engineer might decide to use an existing road if little detrimental effect will be caused by the additional traffic loading.

The second category relates to the construction of a temporary facility, usually parallel to the existing facility. This type of detour is usually removed when no longer needed. In some cases, it might become the base of the permanent structure. Estimating the traffic loading over a time frame is not easy in these cases. Some engineers request the information from TPP. However, for a typical detour, the traffic data used for the parent project will be sufficient. In some cases, the falling weight deflectometer (FWD) is being utilized in evaluating the adequacy of any existing structure to carry detour traffic. Some other considerations for the selection process include the following:

1. ensuring that there is an adequate pavement width to insure wheel loads do not encroach upon the pavement edge;

2. ensuring that there is a properly prepared subgrade (including investigation into soil properties;
3. stabilizing the subgrade, if necessary;
4. ensuring that there is adequate drainage;
5. ensuring that there are properly compacted pavement lifts; and
6. ensuring that there is sufficient in-place mixture density at mat joints.

In many cases, if the detour structure is no longer needed, it is milled and recycled and used within the parent project.

6 Conclusions and Recommendations

6.1 Nationwide DOT Survey Conclusions

1. Most states indicated that there is not a major difference when comparing the daytime paving verses nighttime paving considering the cost and availability of law enforcement officials for work zones.
2. Many states indicated that they do not have enough data to determine the safety issues during daytime paving verses nighttime paving. However, almost half of the states surveyed concluded that the daytime paving is safer than nighttime paving. They also reported that the nighttime paving operation is more expensive than the daytime paving.
3. Almost half of the states responding to the survey indicated that there is not a major issue regarding the staff availability either for the nighttime paving or the daytime paving. The other half of the states indicted that it is much easier to get the staff for the daytime paving verses nighttime paving operations. In addition, they reported that the cost of the staff during the nighttime paving operation is more expensive than the daytime paving.
4. Most states indicated that when comparing the daytime verses nighttime paving, the following three items are considered to be the most important factors: disruption to the traffic, safety of the public, and safety of the workers.
5. The majority of the states indicated that for low volume roads and arterial collector roads they prefer daytime paving operations. However, many of them prefer to conduct the paving during nighttime for the interest systems.
6. Several states indicated that daytime paving operations are easier logistically and yield a better final product; however, many concluded that they do not have enough data to determine the effects on paving time on ease of operation.

6.2 Statewide Contractor Survey Conclusions

1. All of the contractors indicated that the nighttime paving costs are higher than the daytime paving projects.
2. All of the contractors indicated that the worker's costs for the nighttime paving are higher than the daytime paving projects.
3. Majority of the respondents indicated that the traffic has prevented them for moving equipment around the job site during daytime paving projects.
4. Approximately 1/3 of the respondents indicated that in some cases, during the nighttime paving, workers could not be available for the job. In addition, 1/3 indicated that the agency representative was not available to resolve issues and the other 1/3 concluded that inadequate lighting was a major issue.
5. Over 85% of the contractors indicated that the nighttime paving projects takes longer to complete.
6. All of the contractors indicated that the nighttime paving projects are more affected by the weather related issues compared to the daytime paving projects.

6.3 District-Level Conclusions:

6.3.1 District 1 Conclusions

1. The results of the data analysis for District 1 indicates that work zones are set up in such a way that they minimize the distractions of the active work zone to drivers.
2. There was a strong and statistically significant increase in accidents for nighttime projects for District 1.
3. The data strongly indicates that the majority of nighttime accidents occur in active work zones but have low rates of significant injury compared to the daytime paving operations.
4. The only material type with enough data available to perform a district-level analysis on bid price was Base Type A in District 1. For this material in District 1, bid prices for nighttime paving projects were significantly higher than bid prices for daytime paving projects at a 95% confidence level.
5. Nighttime projects exhibited an increased prevalence of passing segments with respect to ride quality in District 1.

6.3.2 District 2 Conclusions

1. For District 2, more information such as traffic flow counts would be needed to assess the accuracy of the conclusion that active work zones in this District are inherently more accident-prone, even though the data suggests that is the case.
2. There was a strong and statistically-significant increase in accidents for nighttime bid projects for District 2.
3. It appears, unlike in District 1, the most severe accidents occur during the day, in inactive work zones that were bid as a nighttime paving project. This could suggest that the way the work zone is setup for nighttime paving operations is different enough compared to the daytime operations that it causes more severe accidents to occur.
4. The nighttime projects had a higher frequency of bonus pay while the daytime bid projects had a higher frequency of 100% pay with respect to ride quality.
5. The ride quality penalty and repair segments for both daytime and nighttime bid projects were approximately equal.

6.3.3 District 3 Conclusions

1. For District 3, the daytime bid projects had a statistically-higher chance of an accident. However, this did not take into account the time of day when a given accident occurred.
2. The ride quality acceptance data for District 3 was generally similar to that of District 2. The nighttime bid projects had a higher frequency of bonus pay while the daytime bid projects had a higher frequency of 100% pay.
3. The ride quality penalty and repair segments for both daytime and nighttime bid projects were approximately equal.

6.3.4 District 4 Conclusions

1. For District 4, the apparent conclusion is that nighttime paving leads to more accidents compared to the daytime, but this can be neither supported nor refuted with sound statistical methodology. This is due to the fact there are not enough data points to conduct a solid statistical analysis.
2. The results also indicated that nighttime bid projects had more ride quality bonus segments while daytime bid projects had more 100% pay segments for this District.

3. The ride quality penalty and repair segments for both daytime and nighttime bid projects were approximately equal.

6.3.5 District 5 Conclusions

1. For District 5, the results of the analysis indicate that the activity level has no statistical influence on the cause of accidents.
2. The nighttime bid projects had a statistically higher chance of an accident. Coupled with other analysis, it appears that nighttime paving projects cause more accidents even if the work zone is inactive. This could be a result of traffic levels, which are unknown, or the procedures used to establish the work zone for nighttime paving operations.
3. District 5's ride quality acceptance data contains slightly different trends than the previously analyzed districts. The daytime bid projects had a much higher prevalence of ride quality bonus segments, while both daytime and nighttime projects had a high overall percentage of ride quality segments receiving 100% pay.
4. Similar to the previous districts, the ride quality penalty and repair segments for both daytime and nighttime bid projects were approximately equal.

6.3.6 District 6 Conclusions

1. For District 6, at first glance there were significantly more accidents in work zones that were bid as night paving projects (579) than in work zones not designated as night paving (22). However, if the time of the accident is considered, there are 433 accidents that occurred during daylight hours and 168 accidents that occurred during nighttime hours. This does not provide the whole story as some crashes occur when there are no workers or activity present.
2. The results of the statistical analysis indicate that the activity level has a statistical influence on the cause of accidents and, unexpectedly, inactive work zones were more prone to accidents. This suggests that the work zone procedures are effective while workers are present, but either something significant happens when the work zone is inactive (e.g. removal of signs) or perhaps less caution is used by drivers with knowledge that the work zone is inactive.
3. Although there was a strong and statistically-significant increase in accidents for nighttime bid projects, this could be due to how work zones are setup for nighttime paving compared to daytime paving or may simply be an artifact of a larger number of nighttime paving projects being contracted.

6.3.7 District 7 Conclusions

1. For District 7, inactive work zones generally exhibited more accidents. This was surprising because it would generally be expected that an active work zone would have a higher rate of accidents due to distractions of the work crews on drivers. It would be interesting to compare the accident data before and after the work zone was setup to determine if there was any statistical change in the accident rate.
2. The analysis also indicated that the most severe accidents occurred during the nighttime hours for nighttime paving projects. This is another indication that the work zone layout may be an issue for nighttime paving operations. It could also be a function of travel levels, but this factor cannot be analyzed with the available data.

3. District 7 is somewhat unusual in that both daytime and nighttime projects had nearly all ride quality segments receiving 100% pay.
4. Daytime projects did have a few ride quality segments that received a bonus, while nighttime projects had no ride quality segments receiving a bonus.
5. As with all the previous districts, the penalty and repair ride quality segments were minimal and comparable between daytime and nighttime projects.

6.4 Statewide Conclusions

1. An overwhelming number of accidents occurred on nighttime paving projects (1,198) compared to daytime paving projects (530). While it is difficult to make a solid conclusion due to the absence of traffic data, it appears that nighttime paving operations do cause significantly more accidents.
2. The analysis directly comparing daytime and nighttime projects shows a statistically-higher accident count for nighttime paving projects.
3. The analysis of data also indicated that regardless of the time of day of the accident, the activity within the work zone itself, or the severity of the injury, there is approximately a 65% chance that any given accident would be at a work zone that was bid as a nighttime paving operation.
4. Overall, it can reasonably be concluded that nighttime paving operations cause statistically higher accident rates at various points throughout the day and night and with various injury severity. A much more thorough analysis could be conducted if traffic flow data for each accident location was provided. Each accident could then be weighted against traffic flow.
5. In general, there appears to be little difference in the bid price between nighttime and daytime construction projects, although the average bid prices for nighttime paving projects were higher for every material type other than OGFC. However, the relatively large standard deviation for most of the bid prices makes any rigorous statistical comparison impossible. Thus, more data is needed to conduct a detailed analysis of this topic.
6. Generally, the average percent within limits (PWL) for in-place density for daytime projects is higher than for nighttime projects, which would indicate higher pavement quality resulting from daytime paving operations, but this conclusion is general in nature and not statistically significant.
7. It is important to note that in nearly every case, the standard deviation for in-place density PWL values for daytime paving was less than the standard deviation for nighttime paving. This suggests that even though, statistically speaking, no comparison can be made of the averages, the fact that the standard deviations are lower for daytime projects indicates a more consistent construction procedure is taking place during daytime paving operations.
8. Nighttime paving projects had significantly more ride quality bonus segments on a statewide basis, while daytime paving projects had significantly more segments receiving 100% pay for ride quality.
9. Similar to the district-level analysis, the penalty and repair ride quality segment differences between daytime and nighttime projects was not substantial.

6.5 Reasonable Detour Conclusions

After contacting several states regarding the detour issues, the following conclusions were made:

1. Most states consider the detour process a very important part of any construction process.
2. They consider if the detour section of the pavement could be used for another purpose.
3. If the detour section cannot be used for a practical purpose after the detour is no longer needed, it is milled and recycled into the construction of the permanent pavement.
4. The engineers must consider many aspects of this detour section from materials and traffic count to the in-place density of the mat.

6.6 Other Conclusions

In addition to the conclusions listed above, the literature review indicated that nighttime paving can cause issues with longitudinal joints and alignment, which can adversely affect both pavement quality and the safety of the driving public on the finished product. Reduced visibility during nighttime paving reduces workers' ability to identify issues with the existing road, trucks, paver alignment, proper tack coat coverage, and mat segregation, which can all adversely affect pavement quality and ultimately reduce the life of the pavement. In addition, reduced visibility makes it more difficult to apply permanent pavement markings in a straight line, which ultimately affects the safety of the driving public.

6.7 Summary of Conclusions:

1. In general, the data indicates that a statistically higher accident count exists for nighttime paving projects compared to daytime paving projects. Overall, it can reasonably be concluded that nighttime paving operations cause statistically higher accident rates at various points throughout the day and night and with various injury severity. In fact, the analysis indicated that there is approximately a 65% chance that any given accident would be in a work zone that was bid as a nighttime paving operation.
2. The bid prices (cost of materials per ton) were higher for all mixture types except OGFC (limited data) for nighttime paving projects compared to the daytime paving projects. However, the relatively large standard deviation for most of the bid prices makes any rigorous statistical comparison impossible.
3. Generally, the average PWL values for in-place density for daytime projects were higher than the average PWL values for nighttime projects, which could indicate that daytime paving operations lead to higher quality pavements. However, this conclusion is only general in nature and not statistically significant.
4. It is important to note that in nearly every case, the standard deviation for in-place density PWL values for daytime paving was less than the standard deviation for nighttime paving. This suggests that even though, statistically speaking, no comparison can be made of the averages, a more consistent construction procedure is taking place during daytime paving operations, which could lead to higher quality pavements.
5. On a statewide basis, nighttime paving projects had significantly more ride quality bonus segments, while daytime projects had a significantly higher number of ride quality segments receiving 100% pay. Generally, the penalty and repair ride quality segment differences between daytime and nighttime projects was not substantial.

6. Detours are a viable option, but engineers must consider many factors including materials, traffic count and in-place density of the mat.
7. Reduced visibility during nighttime paving can adversely affect pavement quality and placement of pavement markings, which can adversely affect pavement life and safety of the driving public on the finished product.

6.8 Recommendations:

The recommendations for this research project include the following:

1. Conduct a study to determine the effects of work zones on drivers' distractions. It is recommended to compare the accident data before and after the work zone was setup to determine if there was any statistical change in the accident rate.
2. Conduct a study regarding the entire data provided in this report and including the traffic flow data for each accident location. It is recommended to develop a model by using each accident and assigning a weight against traffic flow.
3. Conduct a study where more data, including traffic flow and other related information, is used to develop statewide models predicting frequency of the accidents, locations of the accidents and possibly the severity of the injuries due to that accident in the work zone.

7 Appendix A

7.1 State DOTs Nighttime Paving Survey

Name: ____

Agency: ____

Title: ____

Email Address: ____

Phone Number: _______________________________

1. In comparison to daytime law enforcement availability for work zones, is there a difference in nighttime paving law enforcement availability on average?
    a. Yes, it is significantly easier to have law enforcement personnel on site during daytime paving operations
    b. Yes, it is significantly easier to have law enforcement personnel on site during nighttime paving operations
    c. No, it is of no significant effort to have law enforcement on site during both daytime and nighttime paving operations
    d. Other comments____
2. In comparison to daytime law enforcement costs for work zones, is there a difference in nighttime law enforcement costs on average?
    a. Yes, daytime law enforcement costs are higher
    b. Yes, nighttime law enforcement costs are higher
    c. No, law enforcement costs are similar for both daytime and nighttime paving
    d. Other comments____
3. In general, your agency's opinion is that:
    a. Daytime paving is safer than nighttime paving
    b. Nighttime paving is safer than daytime paving
    c. We don't have enough data to come to any conclusion
4. In comparison to daytime paving costs, is there a difference in nighttime paving costs on average?
    a. Yes, daytime paving material costs are higher
    b. Yes, nighttime paving material costs are higher
    c. No, paving material costs are similar for both daytime and nighttime paving
    d. We do not track daytime vs. nighttime paving costs
    e. Other comments____

5. In comparison to daytime paving agency staff availability, is there a difference in nighttime paving agency staff availability on average?
    a. Yes, it is significantly easier to have agency personnel on site during daytime paving operations
    b. Yes, it is significantly easier to have agency personnel on site during nighttime paving operations
    c. No, it is of no significant effort to have agency personnel on site during both daytime and nighttime paving operations
    d. Other comments____
6. In comparison to daytime paving agency staff costs, is there a difference in nighttime paving agency staff costs on average?
    a. Yes, daytime paving agency staff costs are higher
    b. Yes, nighttime paving agency staff costs are higher
    c. No, paving agency staff costs are similar for both daytime and nighttime paving
    d. Other comments____
7. When considering between daytime and nighttime paving operations, please rate how each factor is considered in the selection. The scale is 1 to 10 with 1 indicating the factor has no influence on the decision, 5 indicating there is some influence on the decision, and 10 indicating the factor always has a strong influence on the decision.
    a. Disruption to traffic______________
    b. Safety of workers________________
    c. Safety of public_________________
    d. Material logistics________________
    e. Lighting___________________
    f. Ambient temperature_____________
    g. Type of construction (i.e. concrete, asphalt)______________
    h. Availability of agency personnel to inspect sites_____________
    i. Transportation Costs_____________
    j. Worker Costs_______________
8. On average, for low volume roads, our agency generally prefers and requests that projects are:
    a. Daytime paving projects
    b. Nighttime paving projects
    c. We do not have a preference
    d. We cannot specify a preference
9. On average, for arterial collector roads, our agency generally prefers and requests that projects are:
    a. Daytime paving projects
    b. Nighttime paving projects
    c. We do not have a preference
    d. We cannot specify a preference

10. On average, for interstate and/or high volume roads, our agency generally prefers and requests that projects are:
    a. Daytime paving projects
    b. Nighttime paving projects
    c. We do not have a preference
    d. We cannot specify a preference
11. In general, your agency's opinion is that:
    a. Daytime paving operations are easier logistically and yield a better final product
    b. Daytime paving operations are harder logistically but yield a better final product
    c. Nighttime paving operations are easier logistically and yield a better final product
    d. Nighttime paving operations are harder logistically but yield a better final product
    e. We do not have enough data to come to any conclusion
    f. Other comments____
12. If you answered a, b, c or d to the previous question, please enclose a copy of or provide a link to the related data.

    ____

13. If your agency has any specifications specifically related to nighttime paving operations, please enclose a copy of or provide a link to the related specification.

    ____

8 Appendix B

8.1 South Carolina's Contractors' Nighttime Paving Survey

Name: ____

Company:
____

Title: ____

Email Address: ____

Phone Number: _______________________________

2. In comparison to daytime paving transportation costs, is there a difference in nighttime transportation costs on average?
    a. Yes, daytime paving transportation costs are higher
    b. Yes, nighttime paving transportation costs are higher
    c. No, paving transportation costs are similar for both daytime and nighttime paving
3. In comparison to daytime paving worker costs, is there a difference in nighttime paving worker costs on average?
    a. Yes, daytime paving worker costs are higher
    b. Yes, nighttime paving worker costs are higher
    c. No, paving worker costs are similar for both daytime and nighttime paving
4. With respect to daytime paving operations, has any of the following affected 50% or more of projects during the past couple of years (check all that apply):
    a. Traffic prevented or delayed material/equipment/worker arrival
    b. Excessive heat resulted in delays due to workers needing more/longer breaks
    c. Traffic noise made communication difficult
    d. Other____
5. With respect to nighttime paving operations, has any of the following affected 50% or more of projects during the past couple of years (check all that apply):
    a. Worker unavailability resulted in delays or understaffed jobsites
    b. Agency staff unavailability resulted in delays due to lack of guidance and/or inspection
    c. Inadequate lighting resulted in difficulties directing equipment and trucks to proper location
    d. Other____
6. In the past three years, have you had construction lane reductions that created queues beyond the anticipated/signed lengths?
    a. Yes
    b. No
    c. Information unavailable

7. In the past three years, have you had traffic accidents in construction zones that created queues beyond the anticipated/signed lengths?
    a. Yes
    b. No
    c. Information unavailable
8. In your experience, how does the construction time of nighttime paving projects generally compare to that of daytime paving projects?
    a. In general, nighttime paving projects take longer to complete.
    b. In general, nighttime paving projects are shorter to complete than daytime projects.
    c. Other comments____
9. In your experience, how does the frequency of weather delays for nighttime paving projects generally compare to those for daytime paving projects?
    a. In general, nighttime paving projects experience more weather delays than daytime projects.
    b. In general, daytime paving projects experience more weather delays than nighttime projects.
    c. In general, nighttime and daytime paving projects experience roughly the same amount of weather delays.
    d. Not sure.
10. What types of traffic alleviation methods do you utilize on paving projects? (please also indicate the type(s) of projects each selected traffic alleviation method is used with)
    a. Lane closure
        i. Low-volume
        ii. Medium volume
        iii. High-volume
    b. Road closure/Detour
        i. Low-volume
        ii. Medium volume
        iii. High-volume
    c. Off-peak hour operations
        i. Low-volume
        ii. Medium volume
        iii. High-volume
    d. Night operations (question continues on next page)
        i. Low-volume
        ii. Medium volume
        iii. High-volume
    e. Other (please specify)____
        i. Low-volume
        ii. Medium volume
        iii. High-volume

9 Appendix C

9.1 Maps of District Work Zone Traffic Accidents

The red dots indicate the location of accidents that occurred in SCDOT work zones in 2012, the blue dots indicate the location of accidents in 2013, and the green dots indicate the location of accidents in 2014.

9.1.1 District 1 Work Zone Traffic Accident Maps

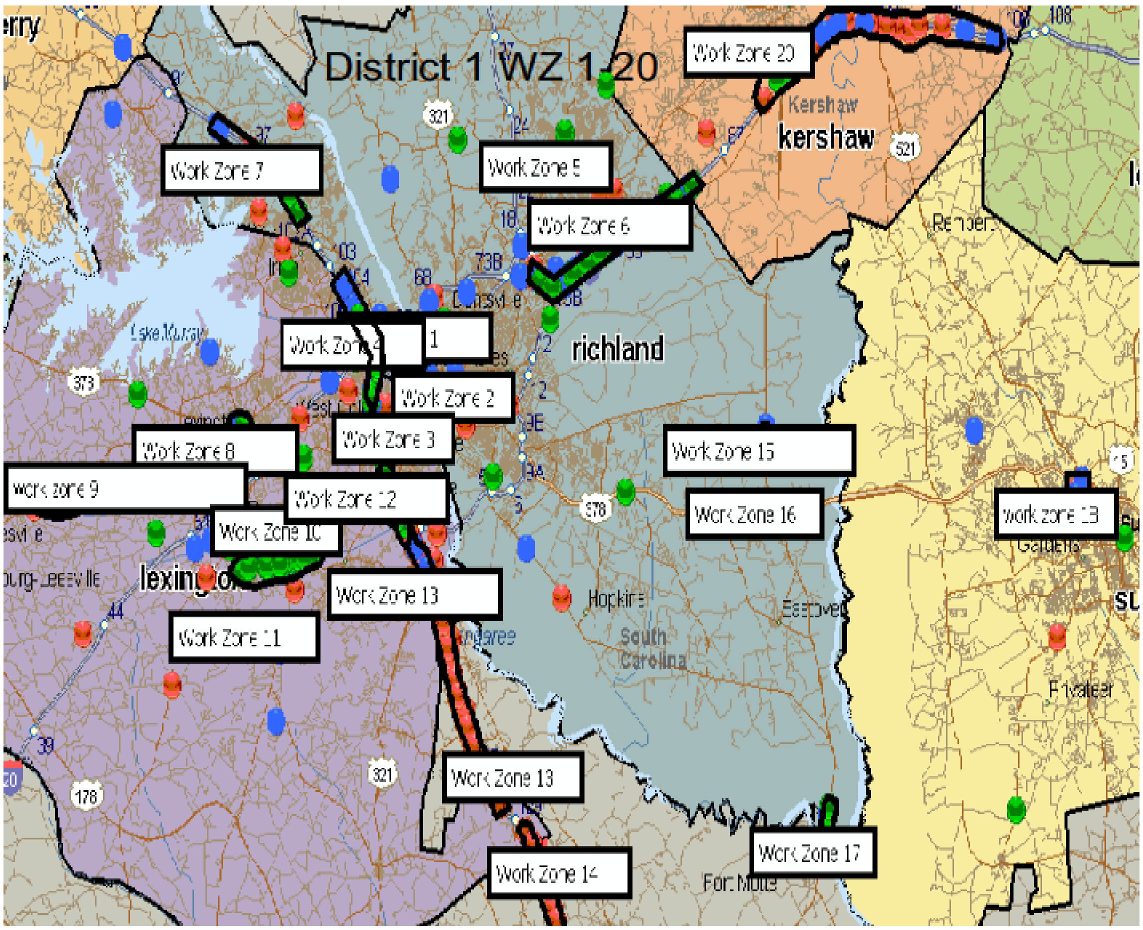


Figure 9-1: District 1 – All Work Zones

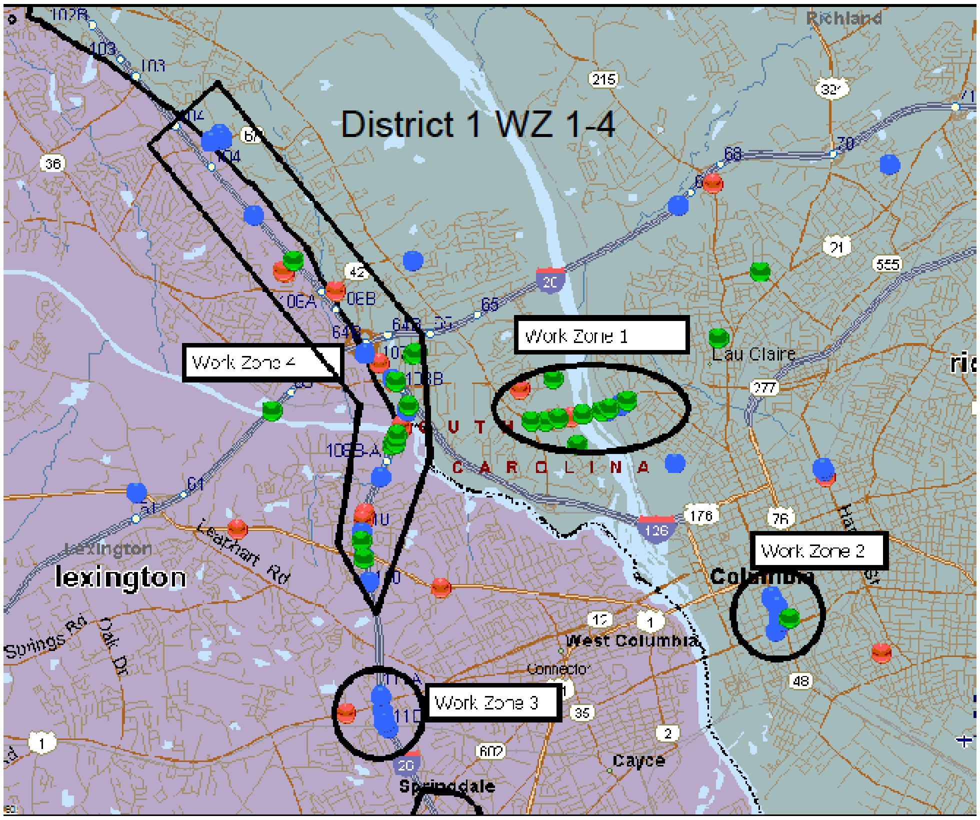


Figure 9-2: District 1 Work Zones 1-4

District 1 WZ 5-6

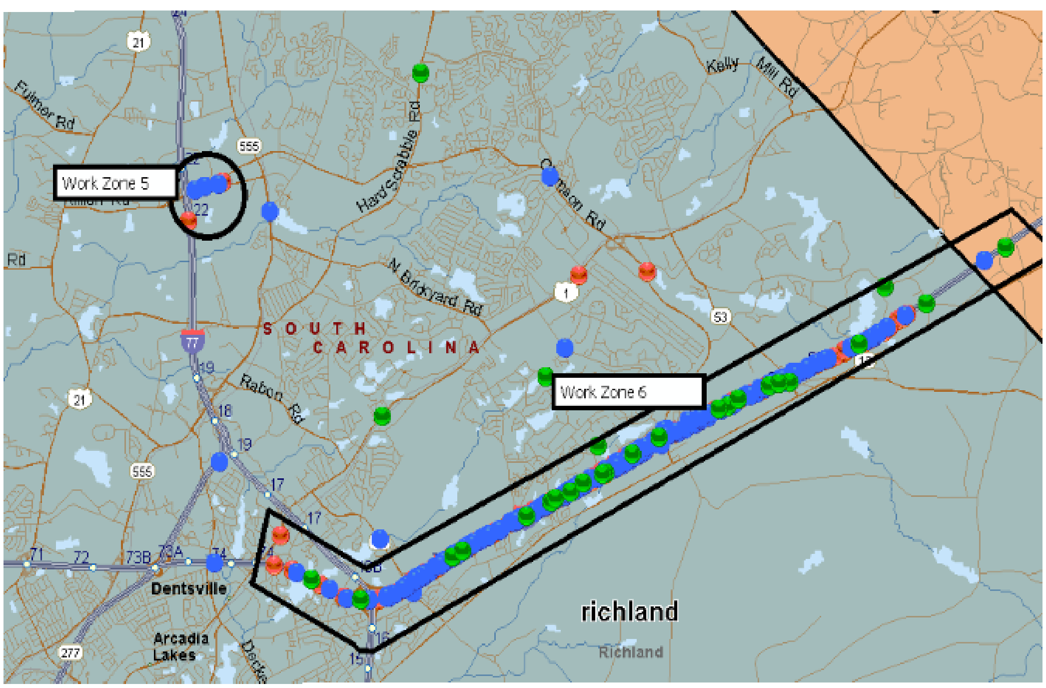


Figure 9-3: District 1 Work Zones 5-6

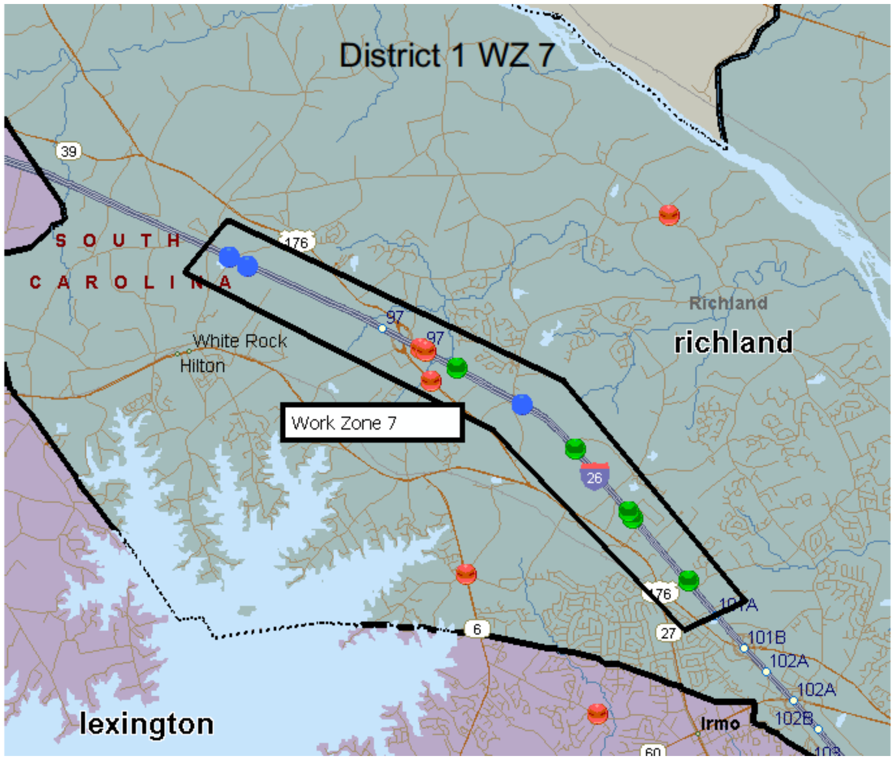


Figure 9-4: District 1 Work Zone 7

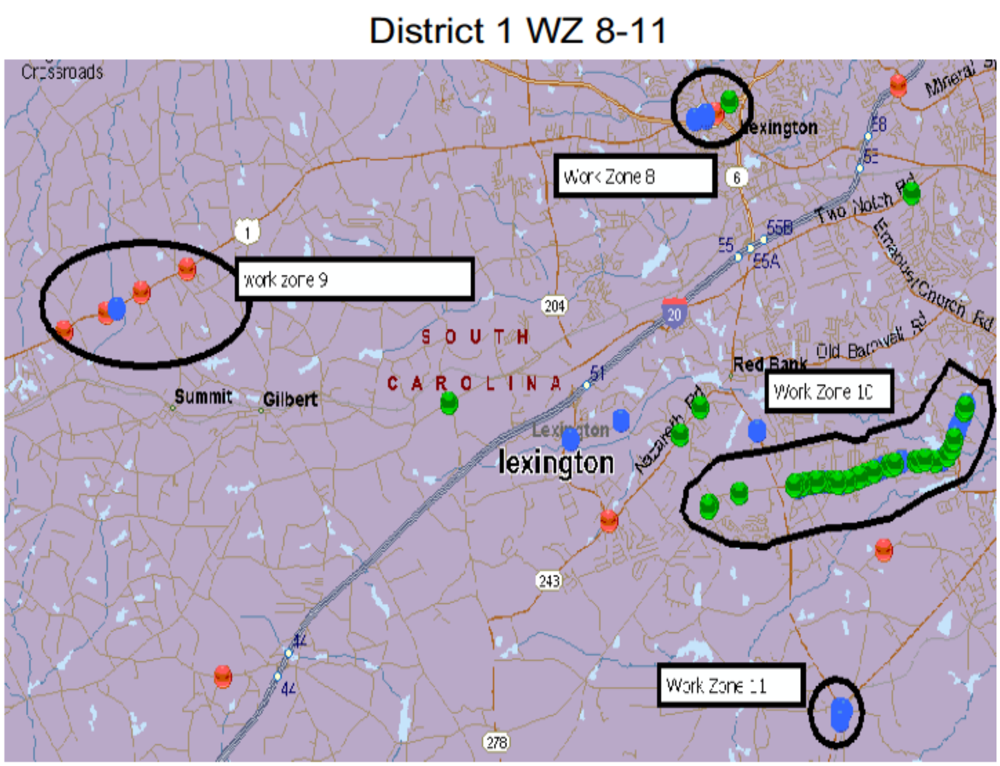


Figure 9-5: District 1 Work Zones 8-11

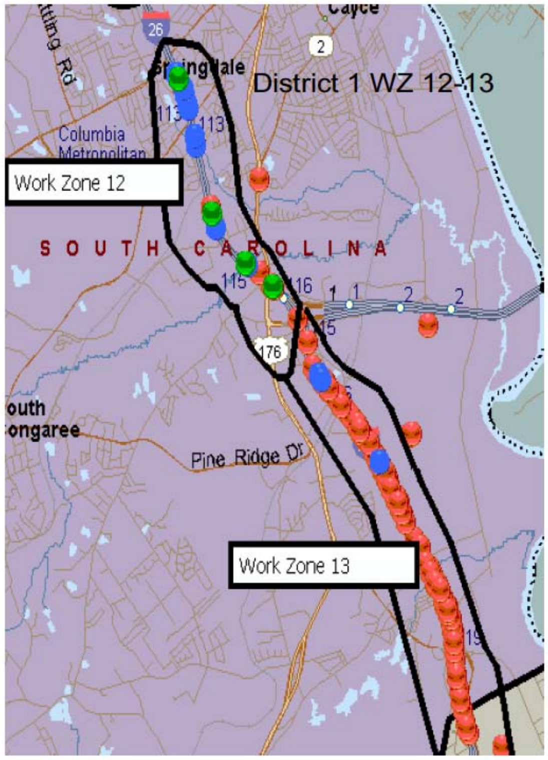


Figure 9-6: District 1 Work Zones 12-13

District 1 WZ 13-14

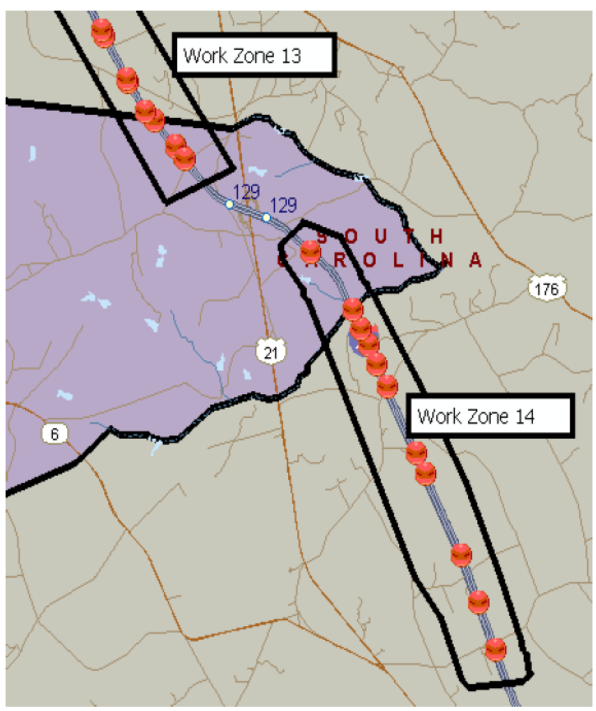


Figure 9-7: District 1 Work Zones 13-14

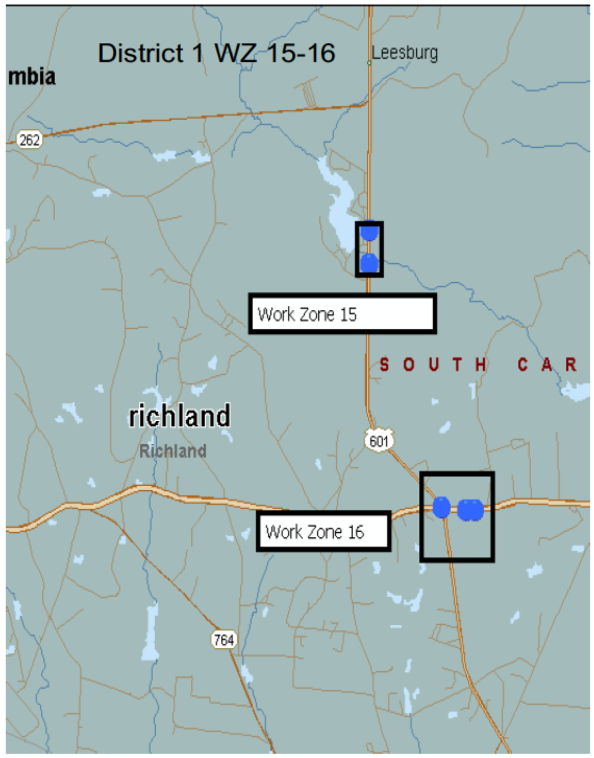


Figure 9-8: District 1 Work Zones 15-16

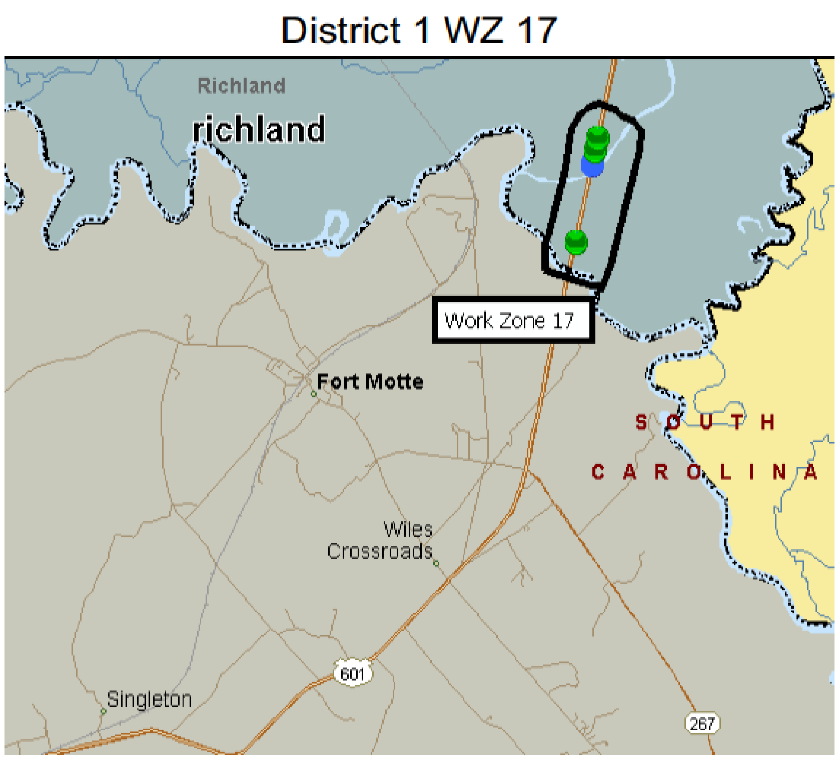


Figure 9-9: District 1 Work Zone 17

District 1 WZ 18

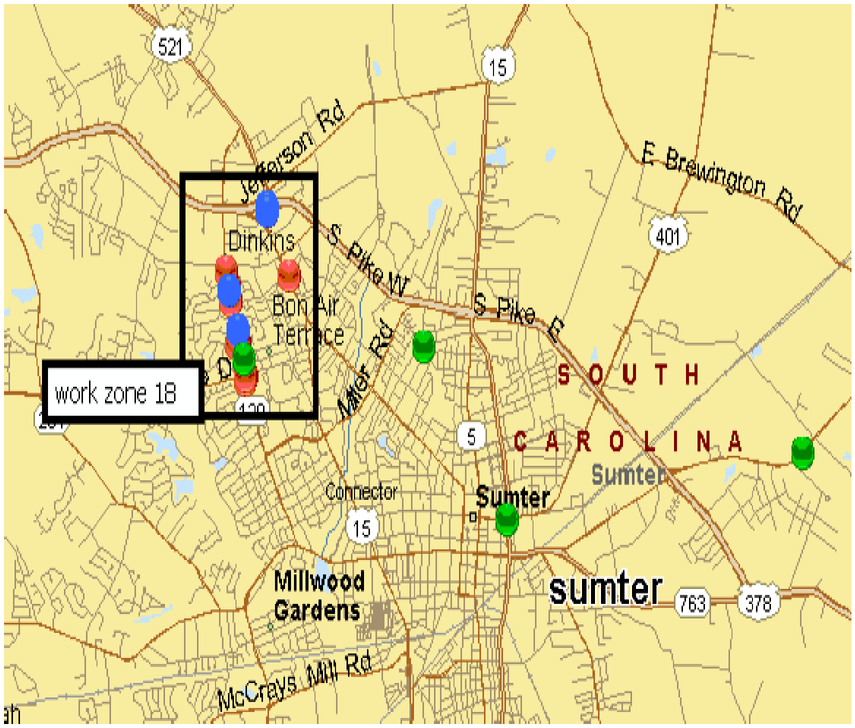


Figure 9-10: District 1 Work Zone 18

District 1 WZ 19

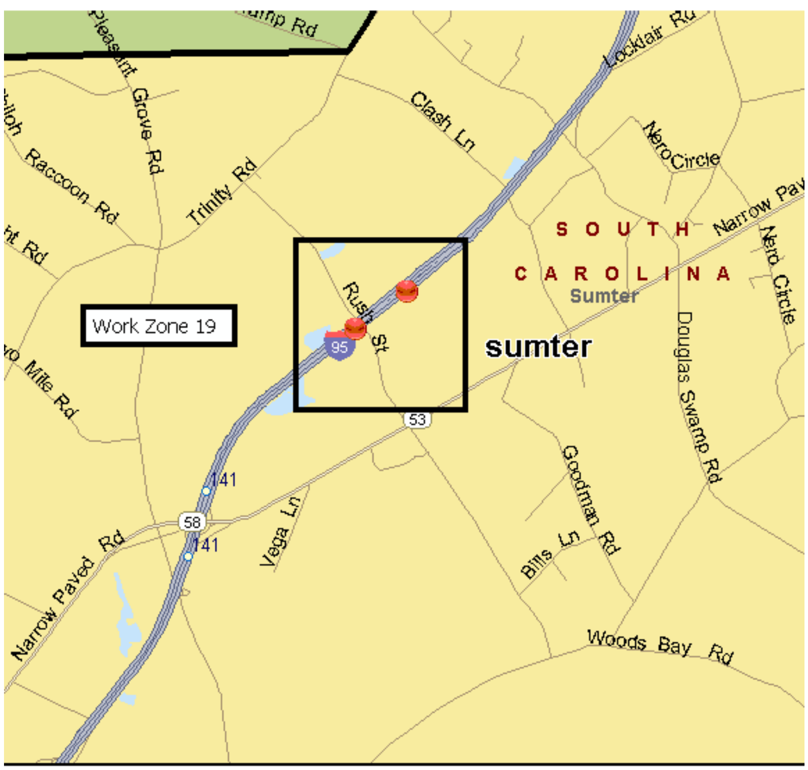


Figure 9-11: District 1 Work Zone 19

District 1 WZ 20

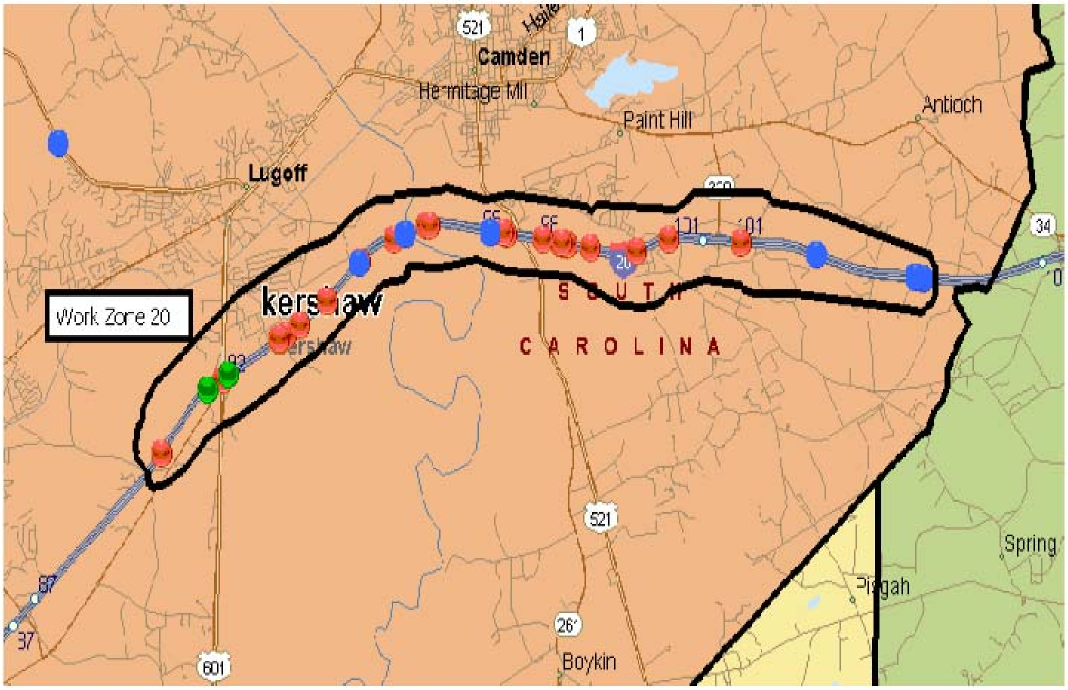


Figure 9-12: District 1 Work Zone 20

9.1.2 District 2 Work Zone Traffic Accident Maps

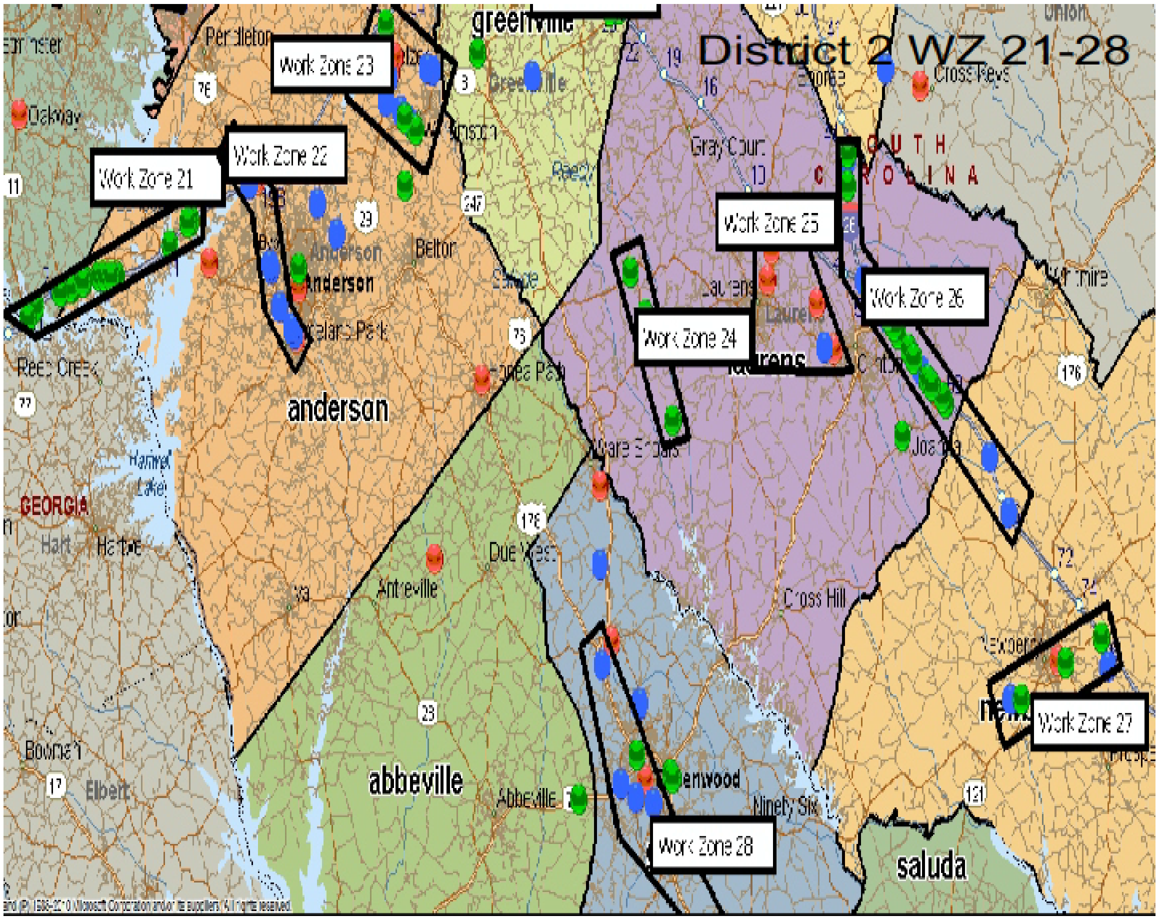


Figure 9-13: District 2 – All Work Zones

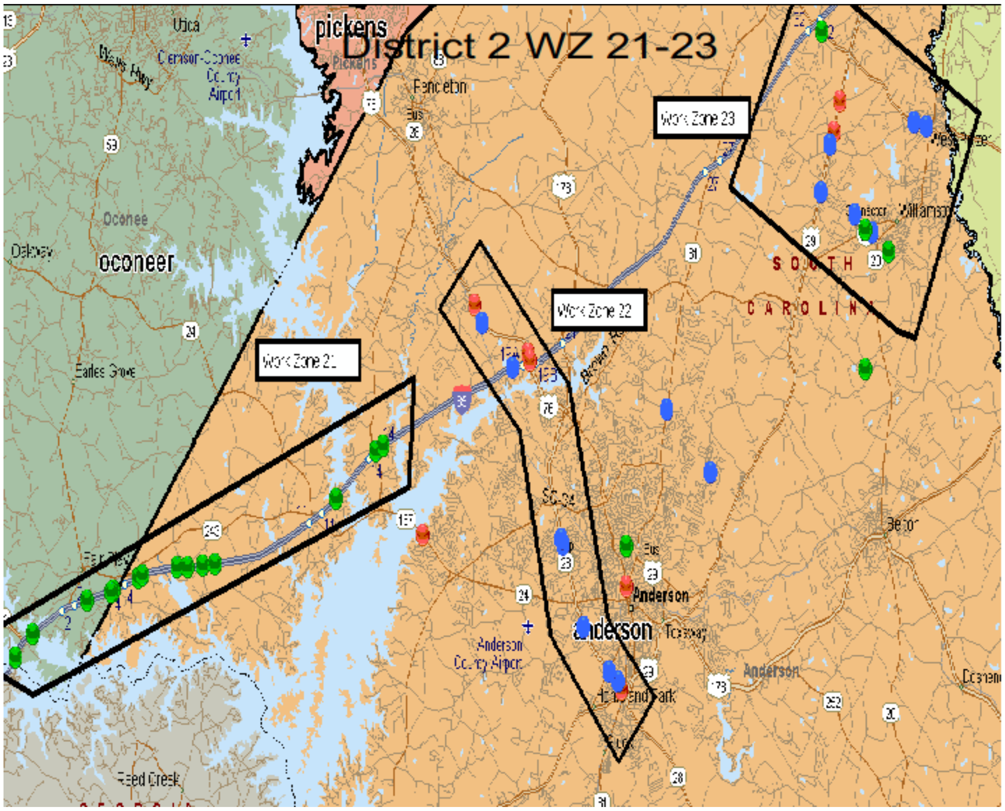


Figure 9-14: District 2 Work Zones 21-23

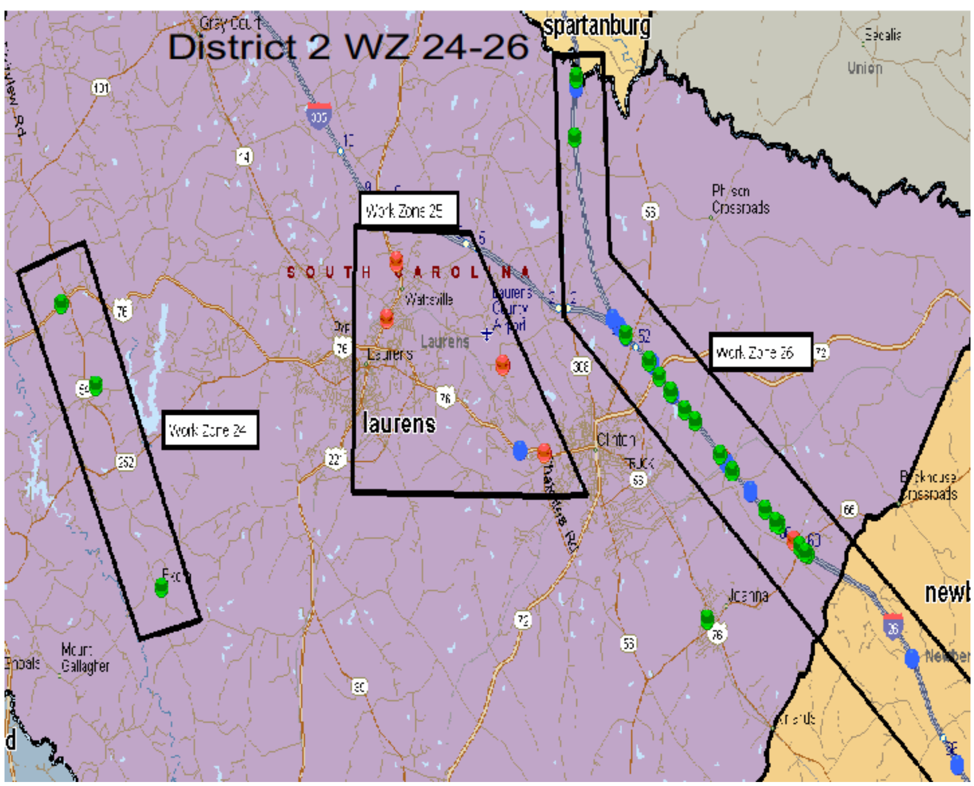


Figure 9-15: District 2 Work Zones 24-26

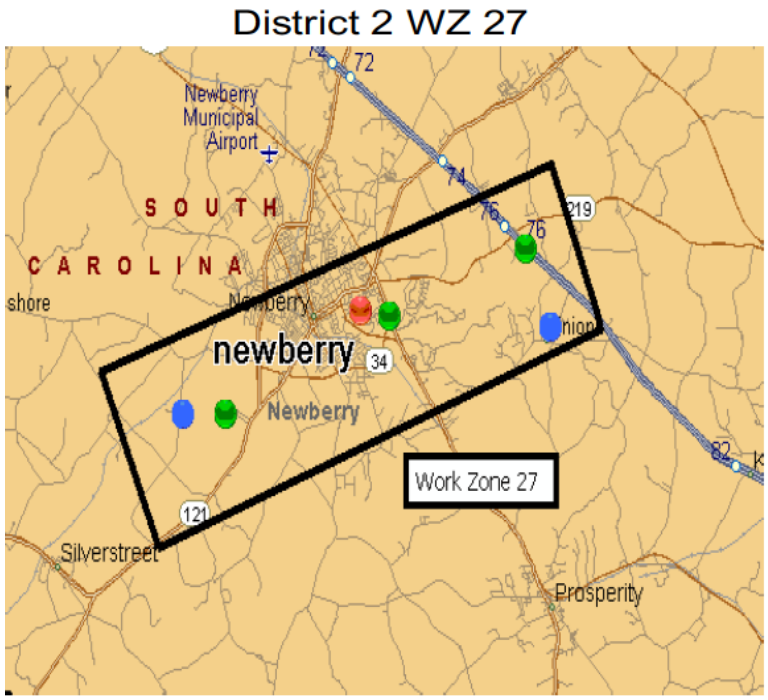


Figure 9-16: District 2 Work Zone 27

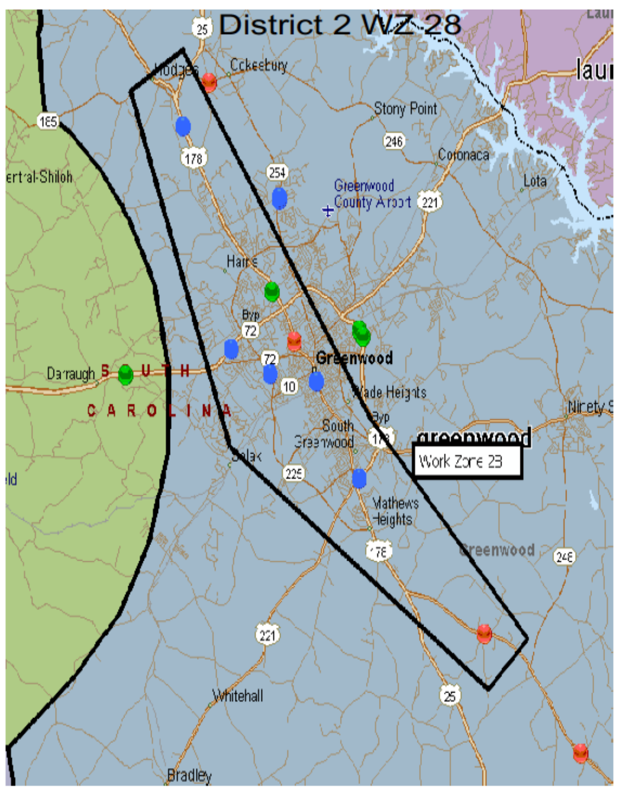


Figure 9-17: District 2 Work Zone 28

9.1.3 District 3 Work Zone Traffic Accident Maps

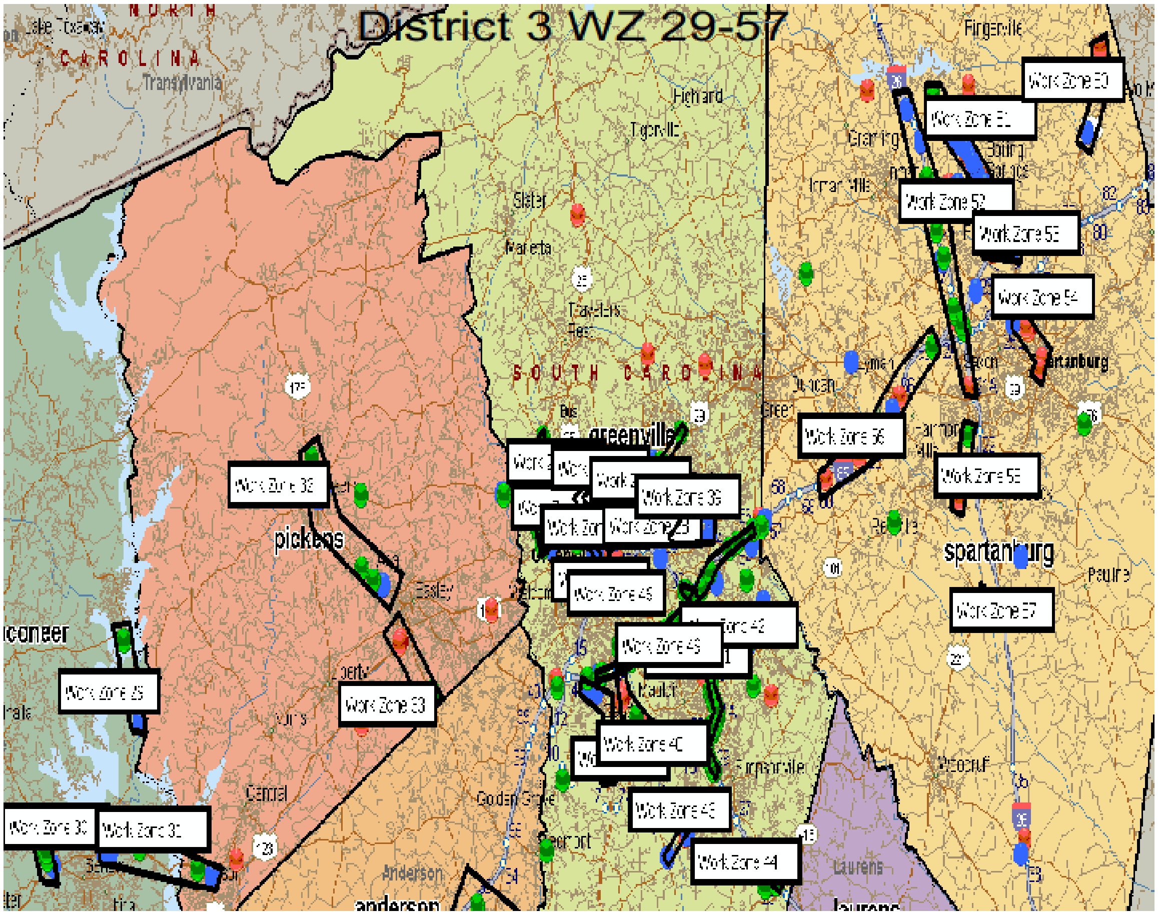


Figure 9-18: District 3 – All Work Zones

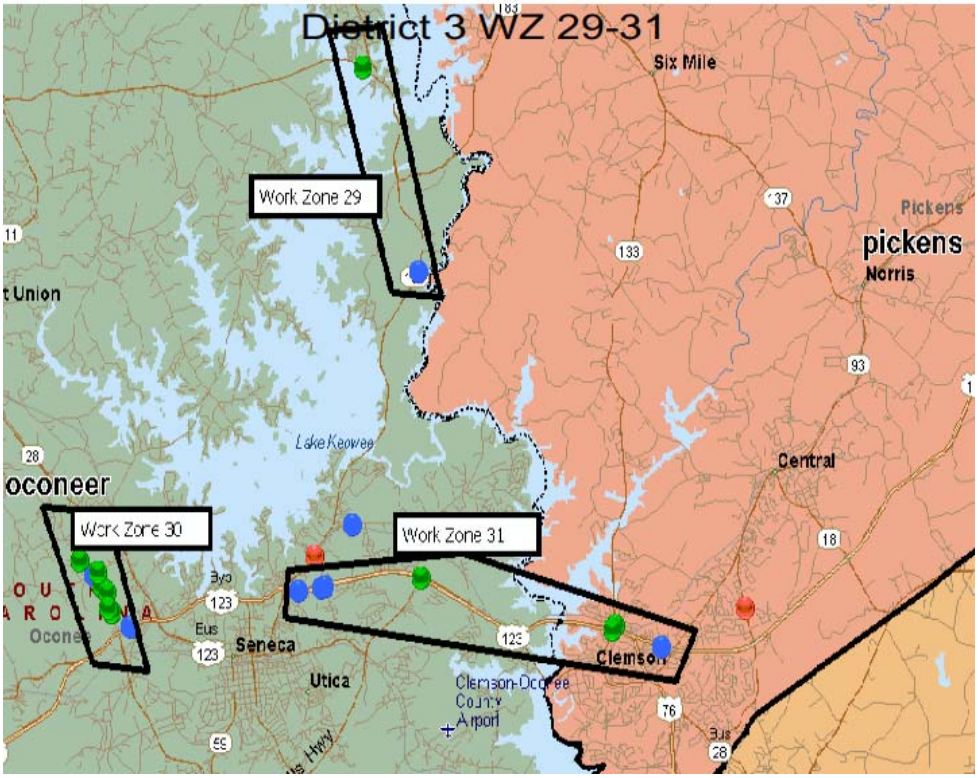


Figure 9-19: District 3 Work Zones 29-31

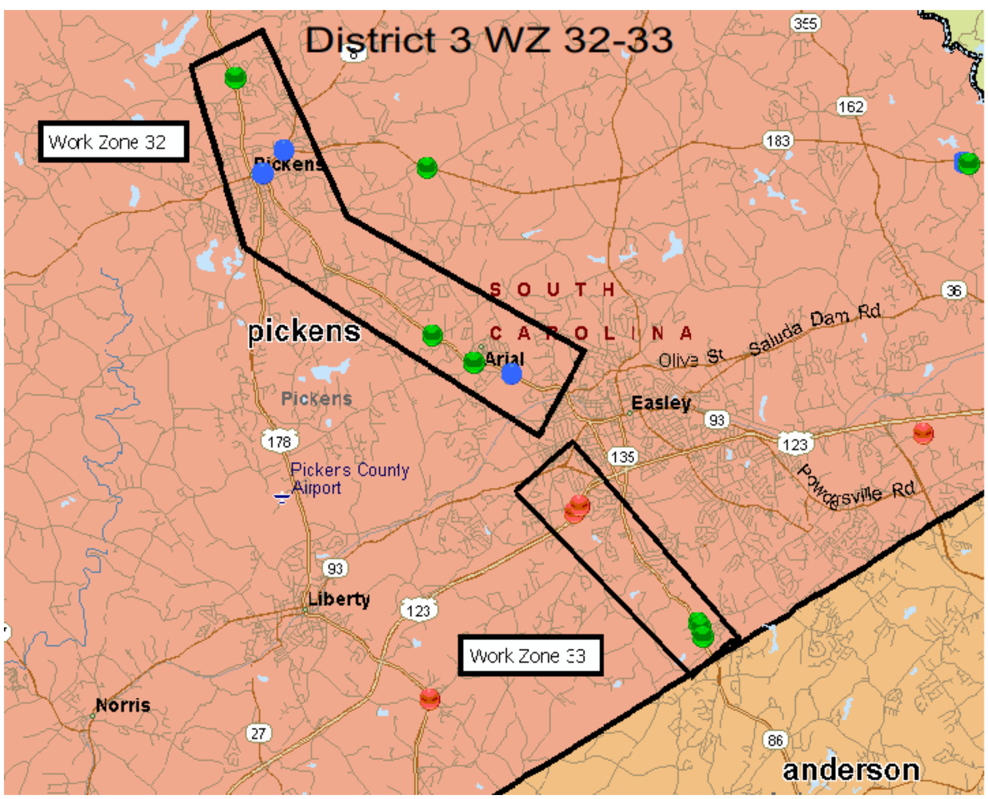


Figure 9-20: District 3 Work Zones 32-33

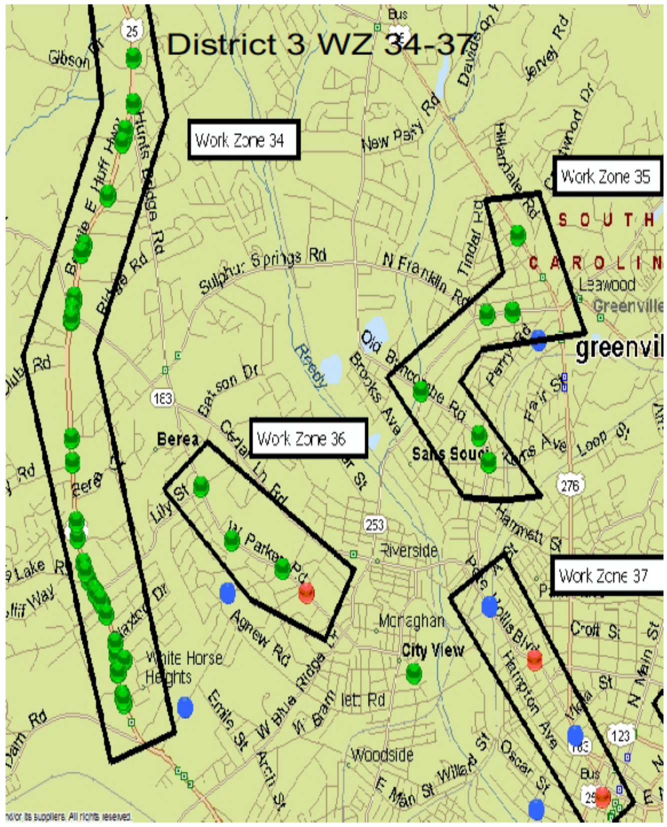


Figure 9-21: District 3 Work Zones 34-37

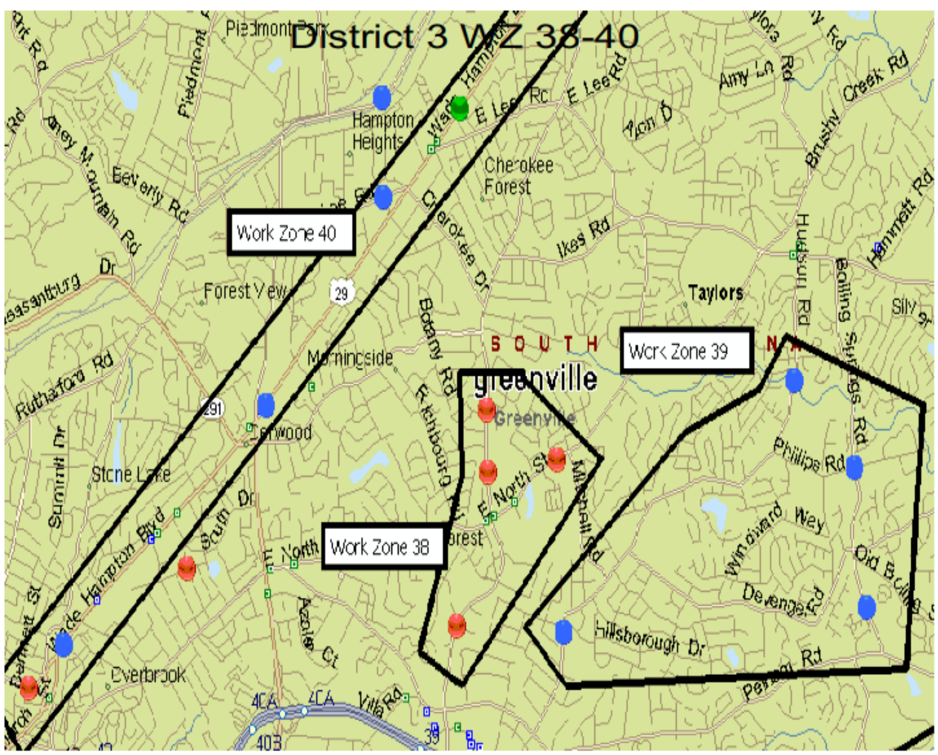


Figure 9-22: District 3 Work Zones 38-40

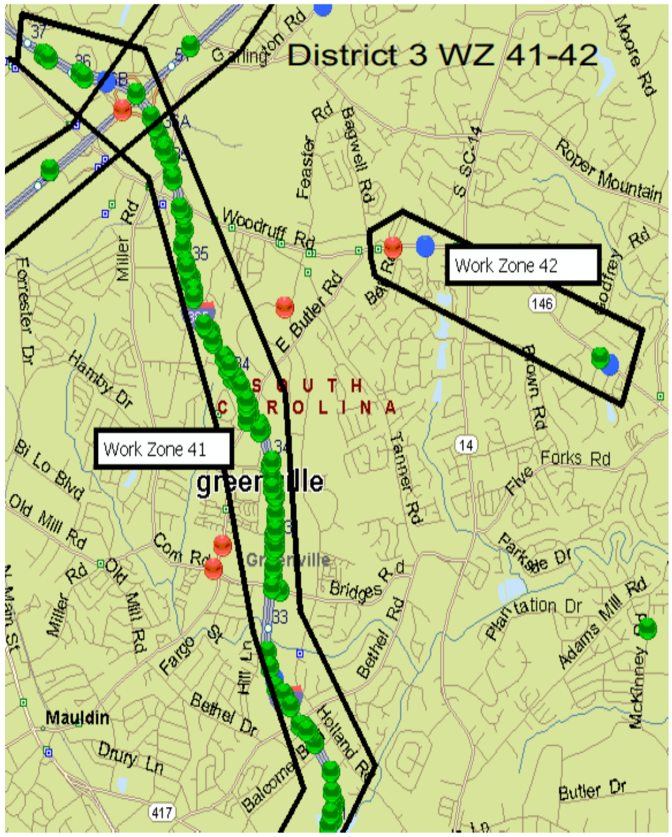


Figure 9-23: District 3 Work Zones 41-42

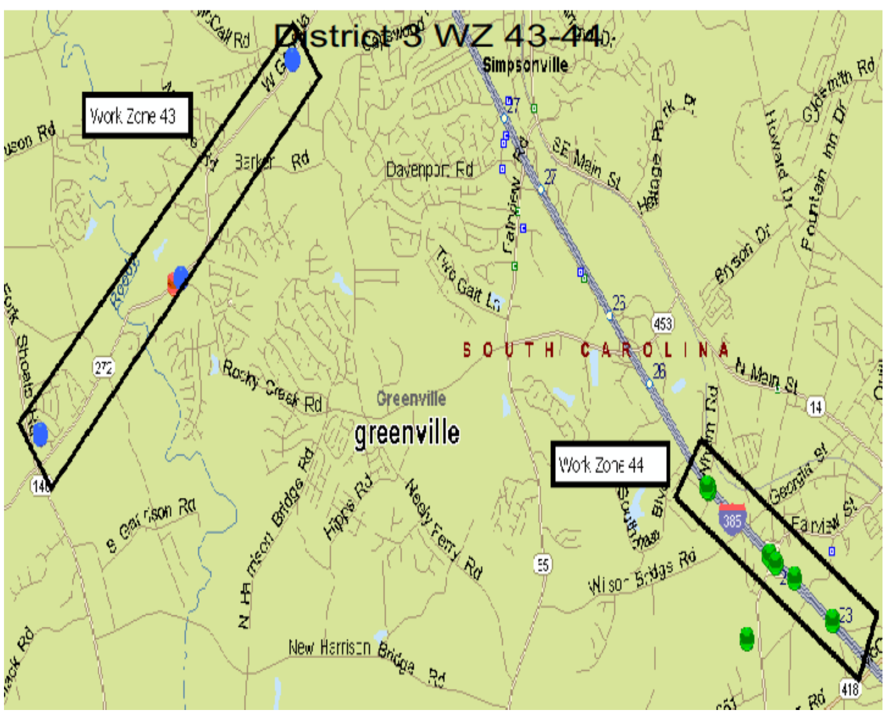


Figure 9-24: District 3 Work Zones 43-44

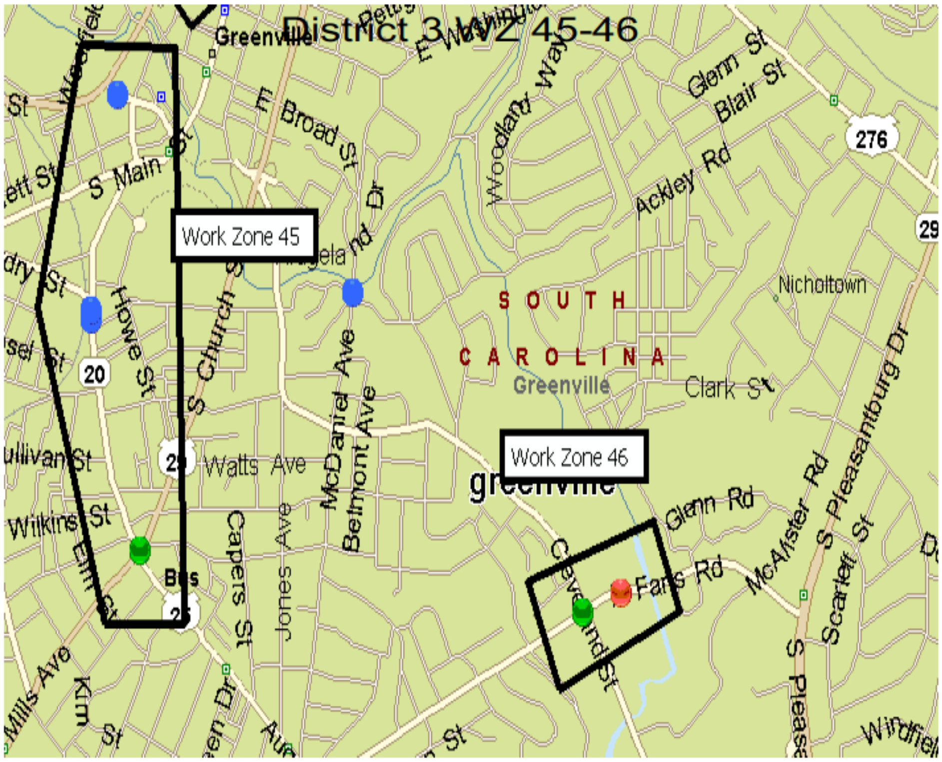


Figure 9-25: District 3 Work Zones 45-46

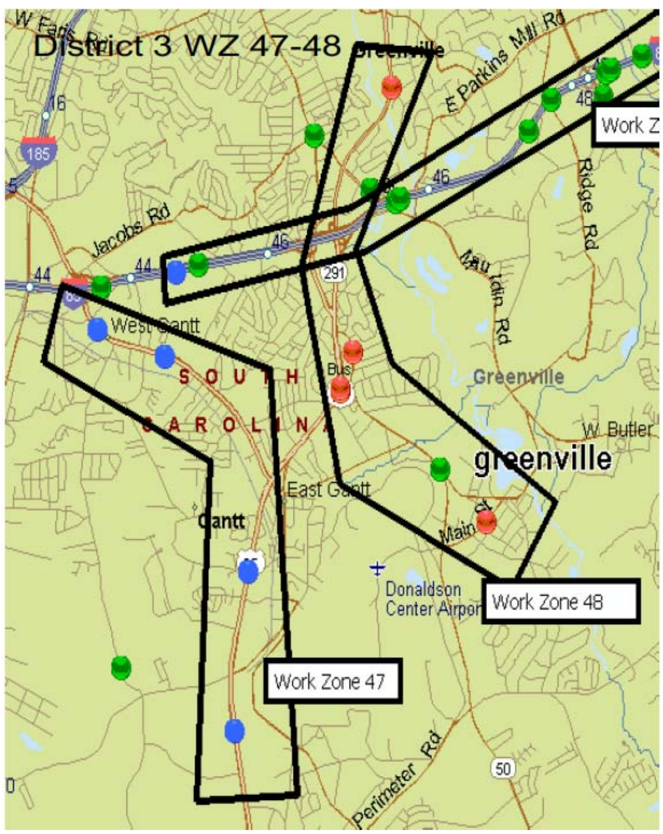


Figure 9-26: District 3 Work Zones 47-48

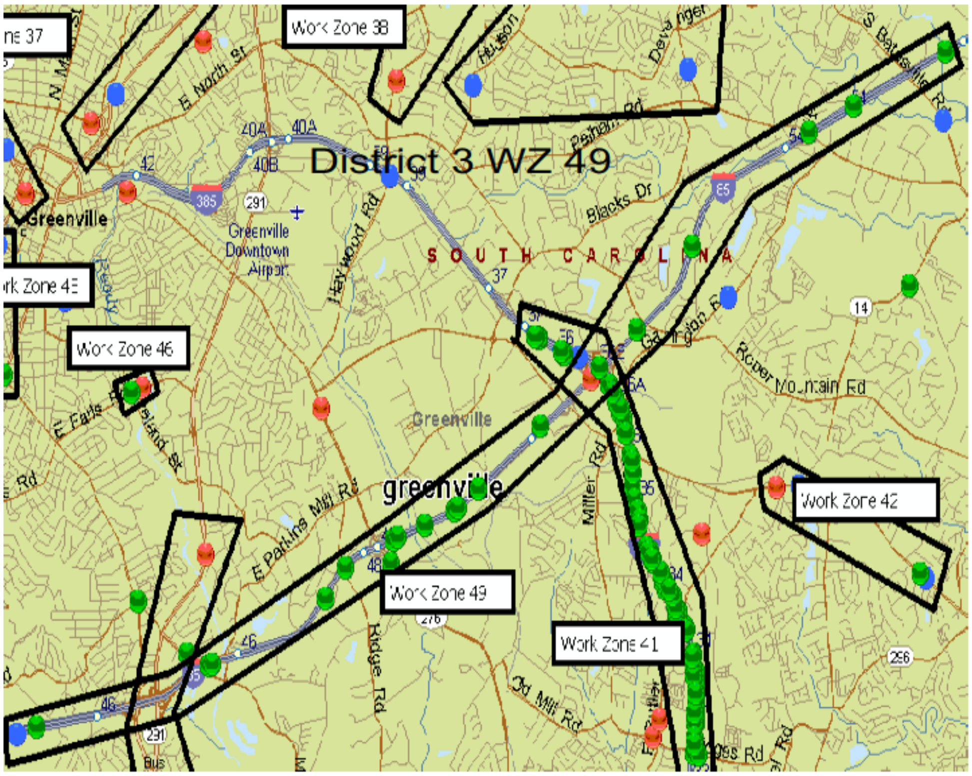


Figure 9-27: District 3 Work Zone 49

District 3 WZ 50

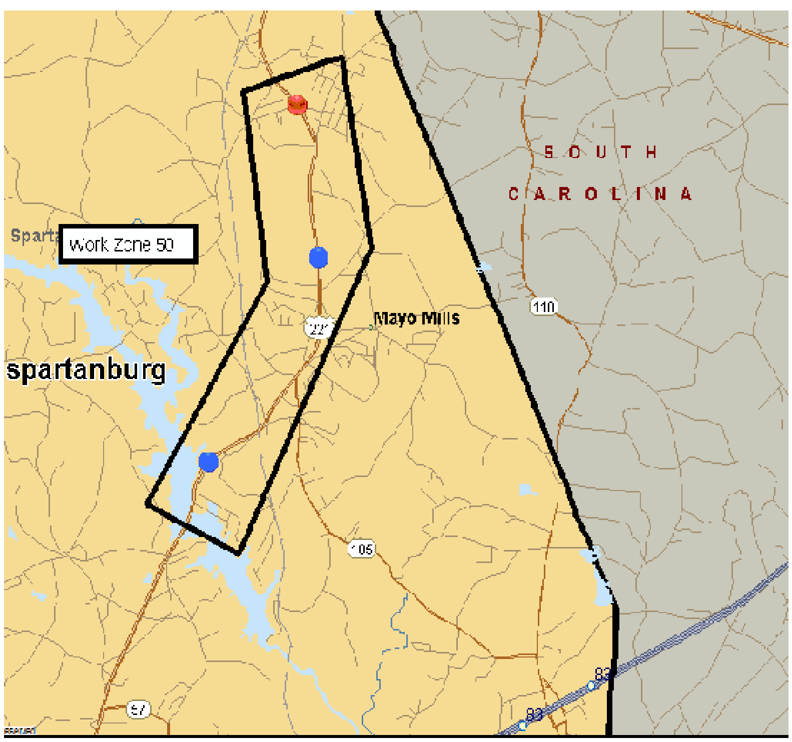


Figure 9-28: District 3 Work Zone 50

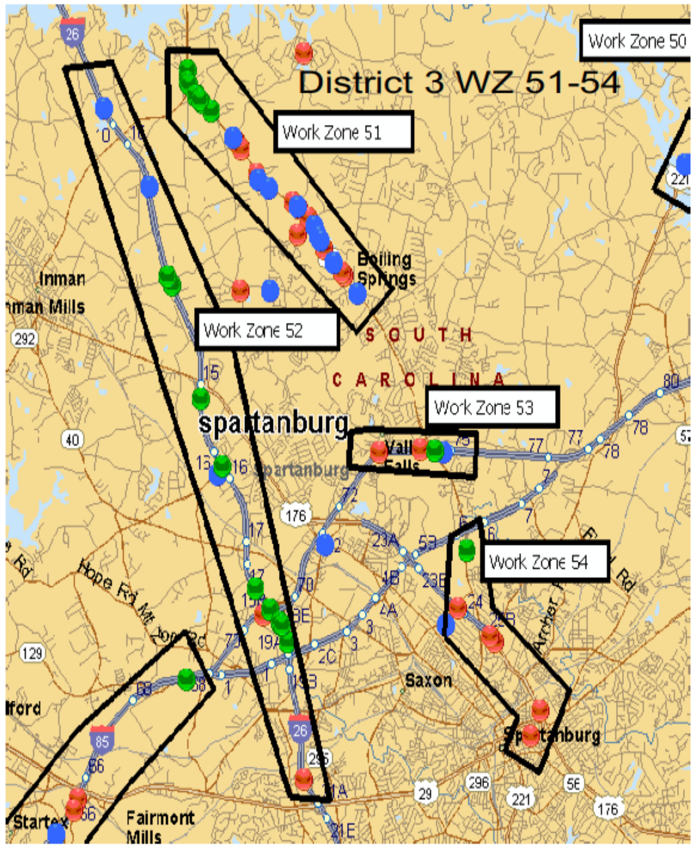


Figure 9-29: District 3 Work Zones 51-54

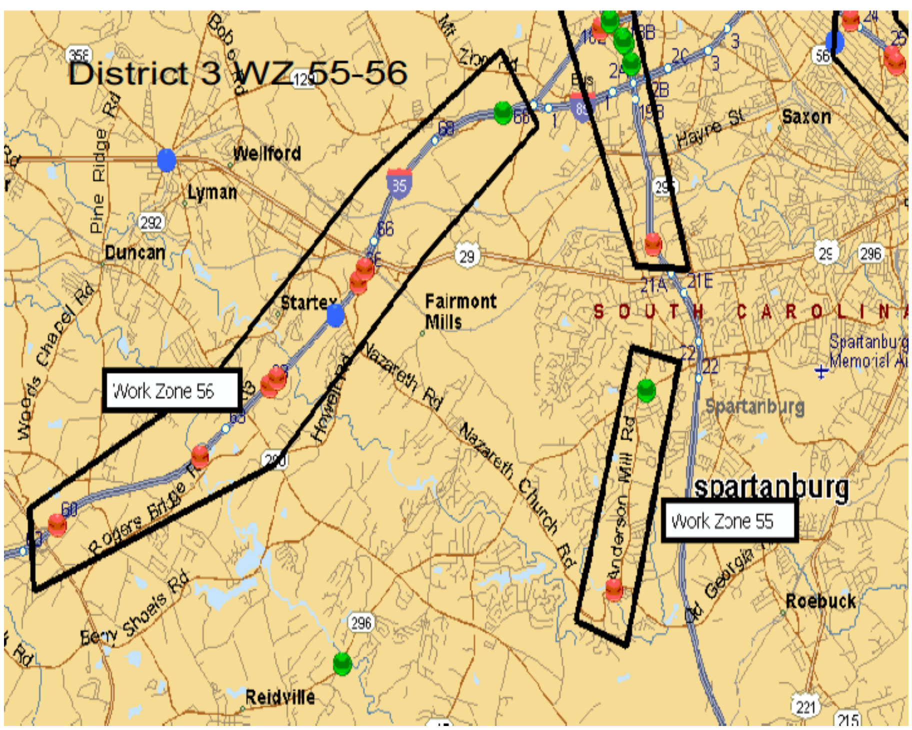


Figure 9-30: District 3 Work Zones 55-56

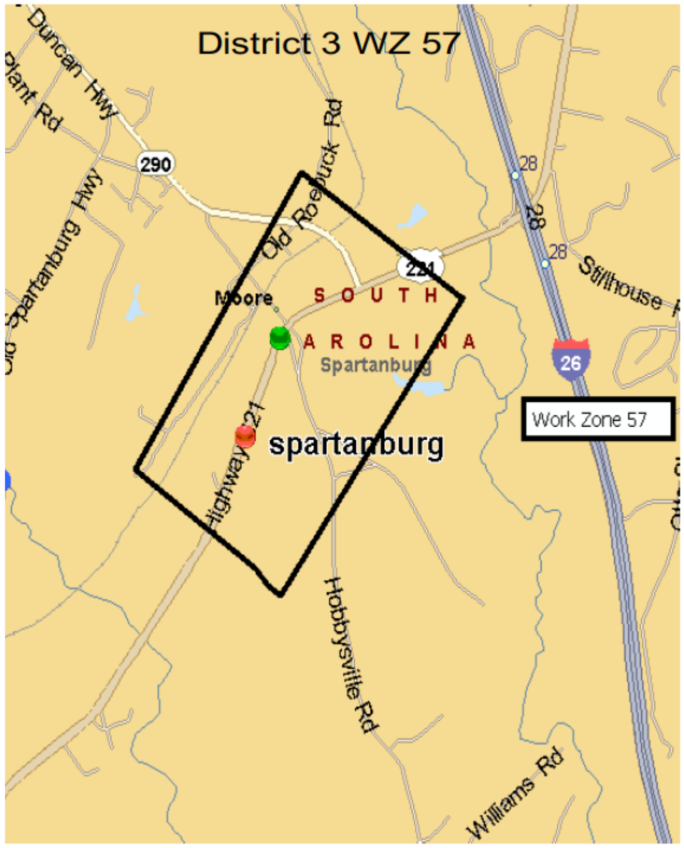


Figure 9-31: District 3 Work Zone 57

9.1.4 District 4 Work Zone Traffic Accident Maps

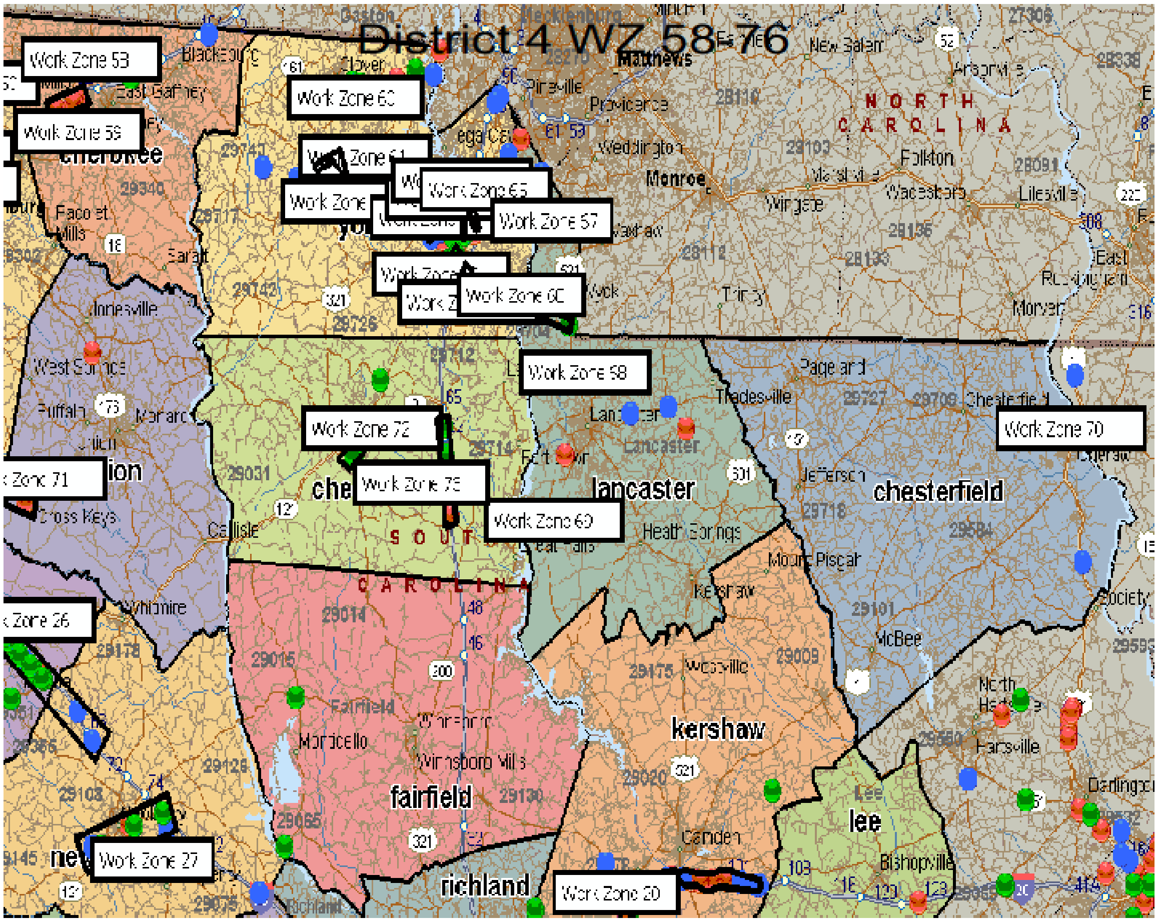


Figure 9-32: District 4 – All Work Zones

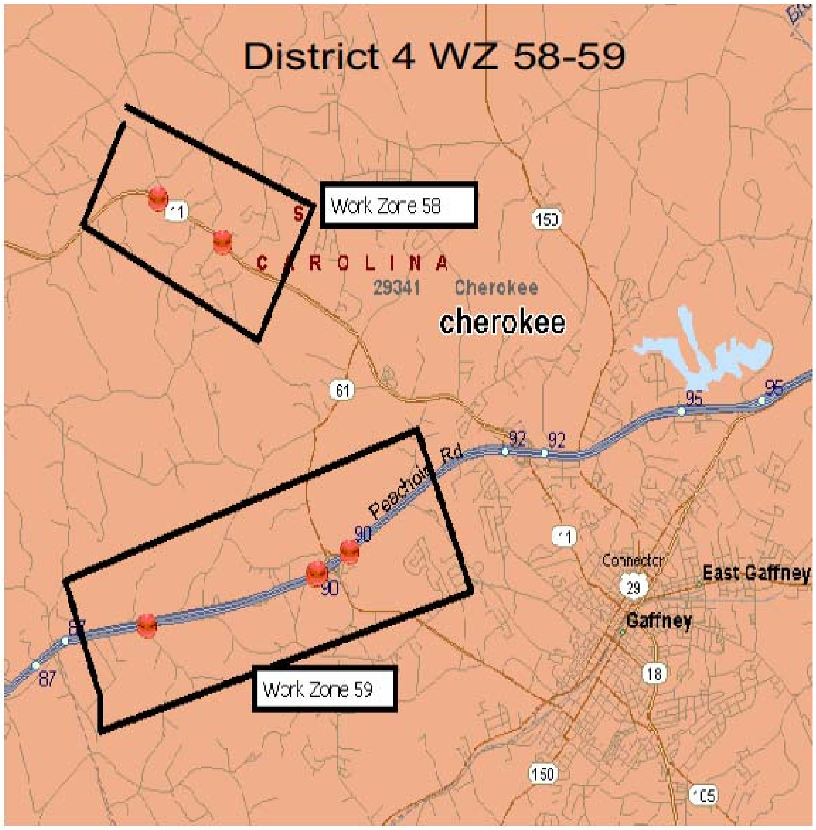


Figure 9-33: District 4 Work Zones 58-59

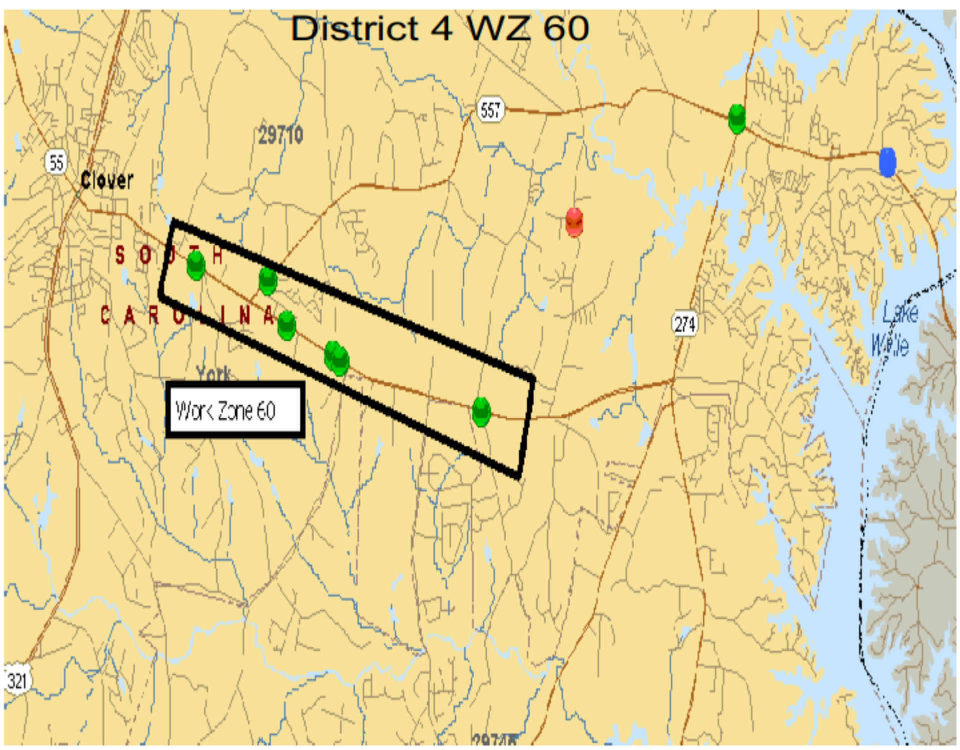


Figure 9-34: District 4 Work Zone 60

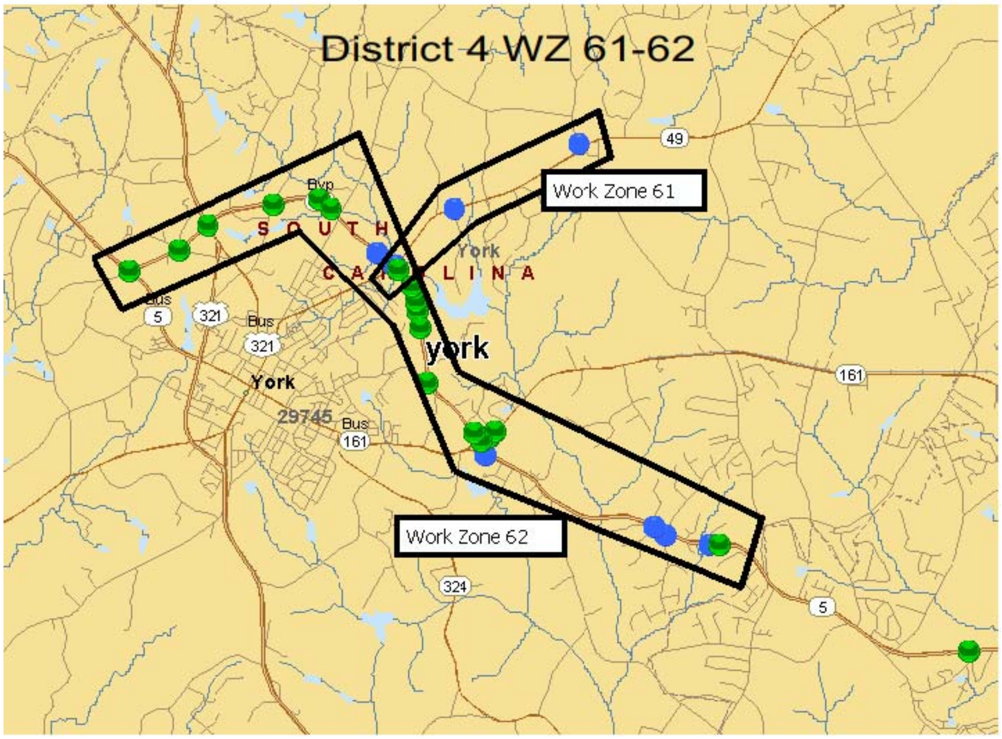


Figure 9-35: District 4 Work Zones 61-62

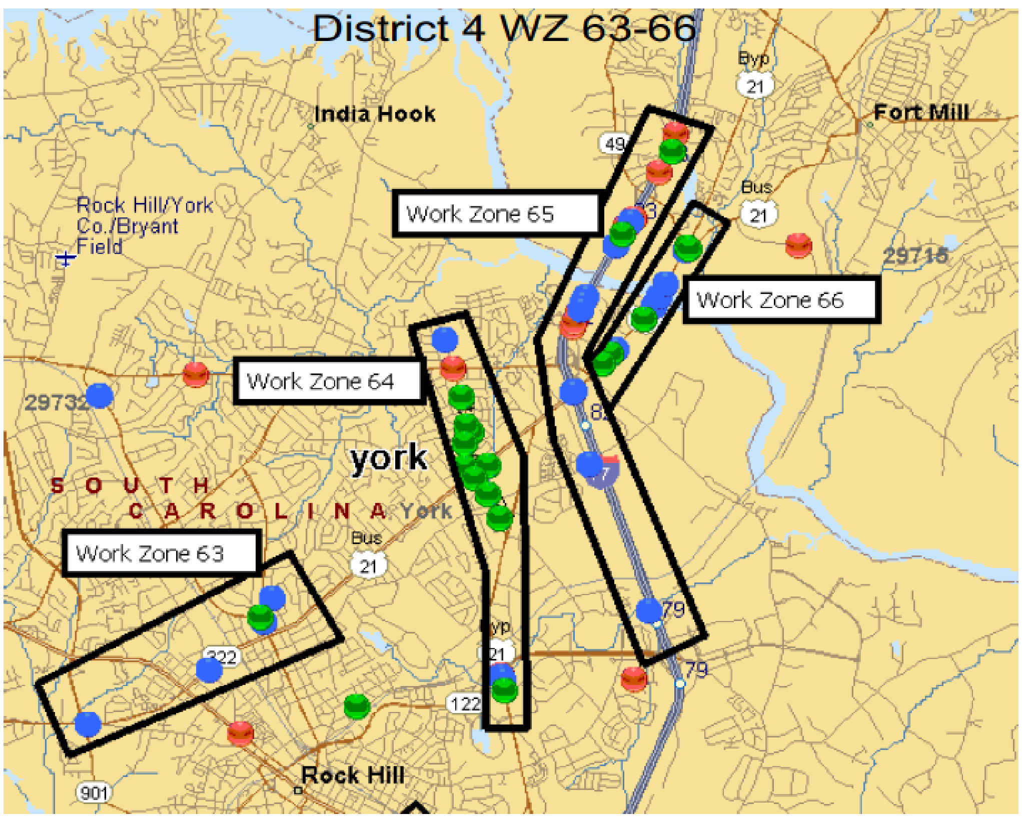


Figure 9-36: District 4 Work Zones 63-66

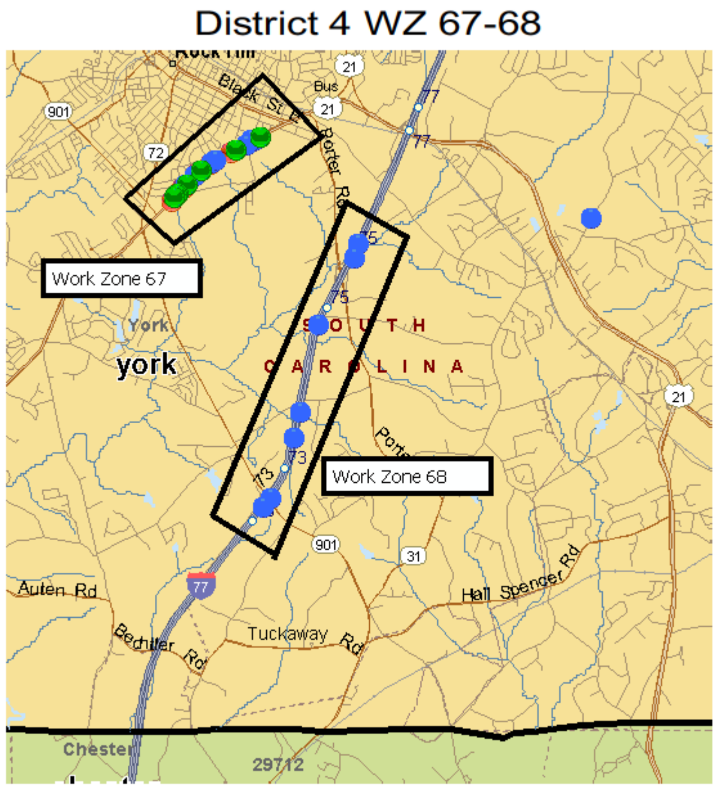


Figure 9-37: District 4 Work Zones 67-68

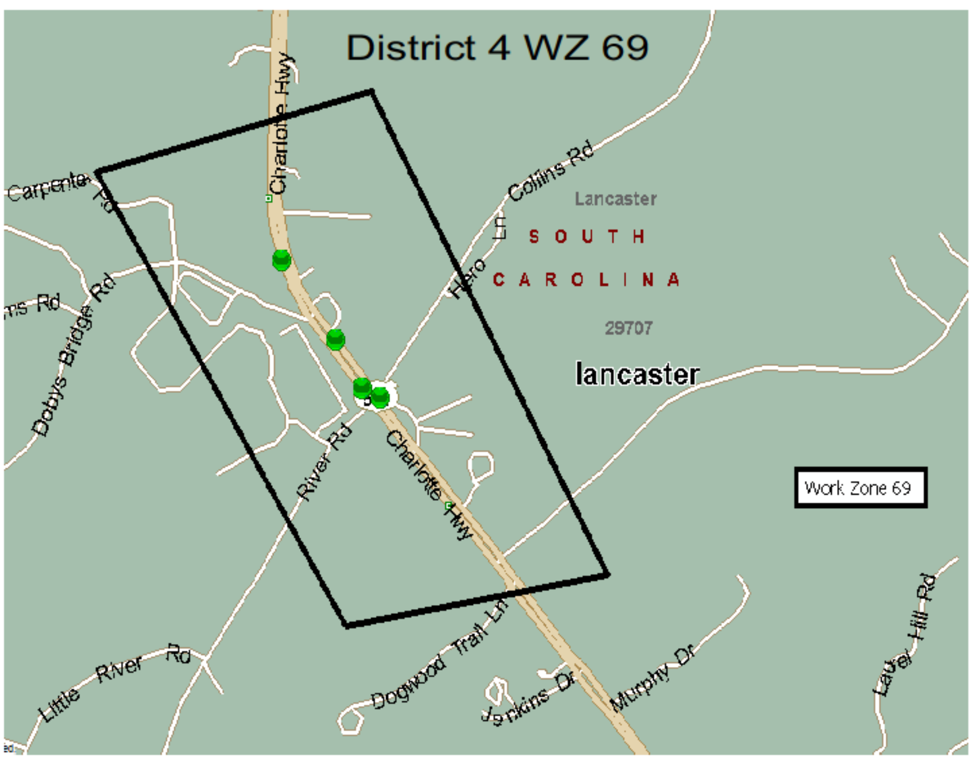


Figure 9-38: District 4 Work Zone 69

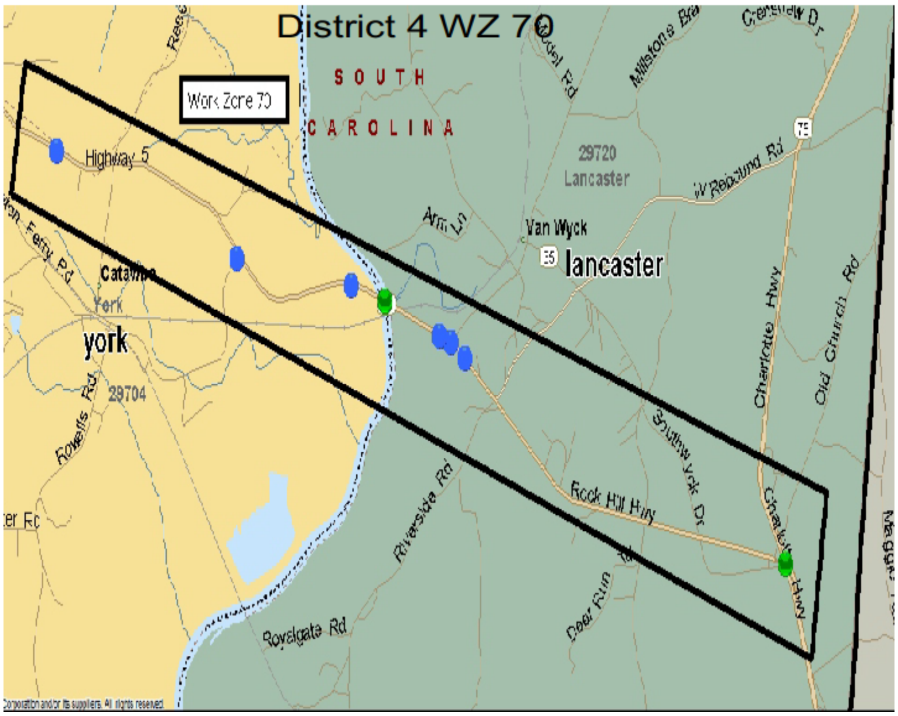


Figure 9-39: District 4 Work Zone 70

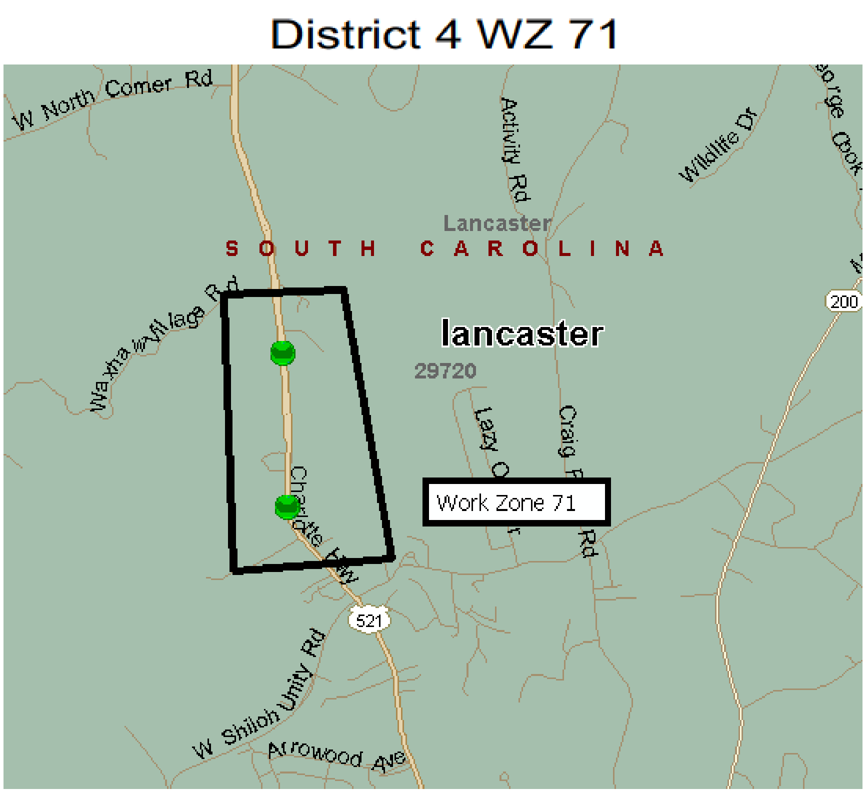


Figure 9-40: District 4 Work Zone 71

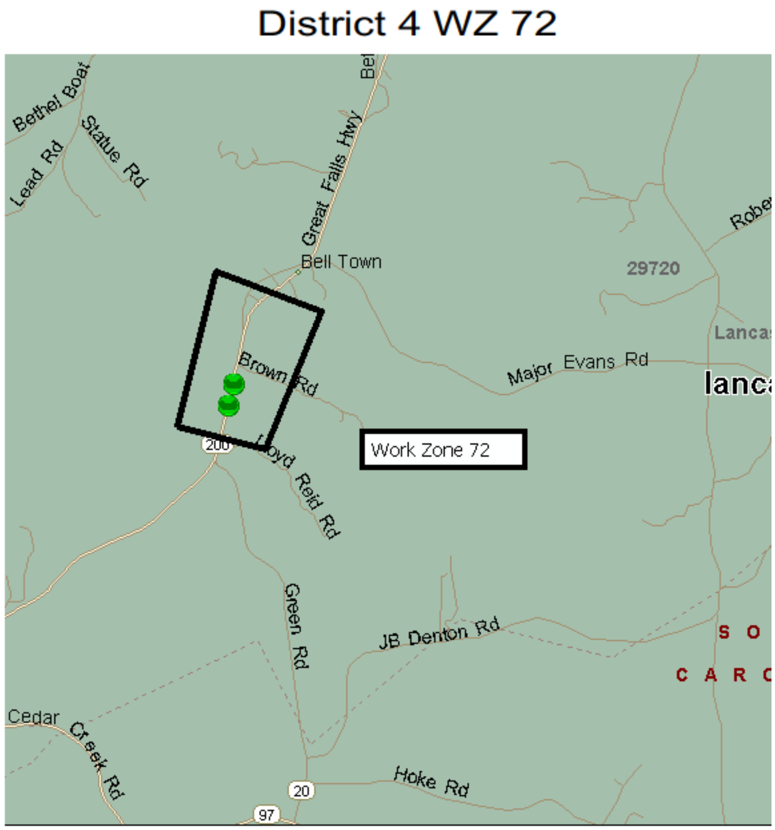


Figure 9-41: District 4 Work Zone 72

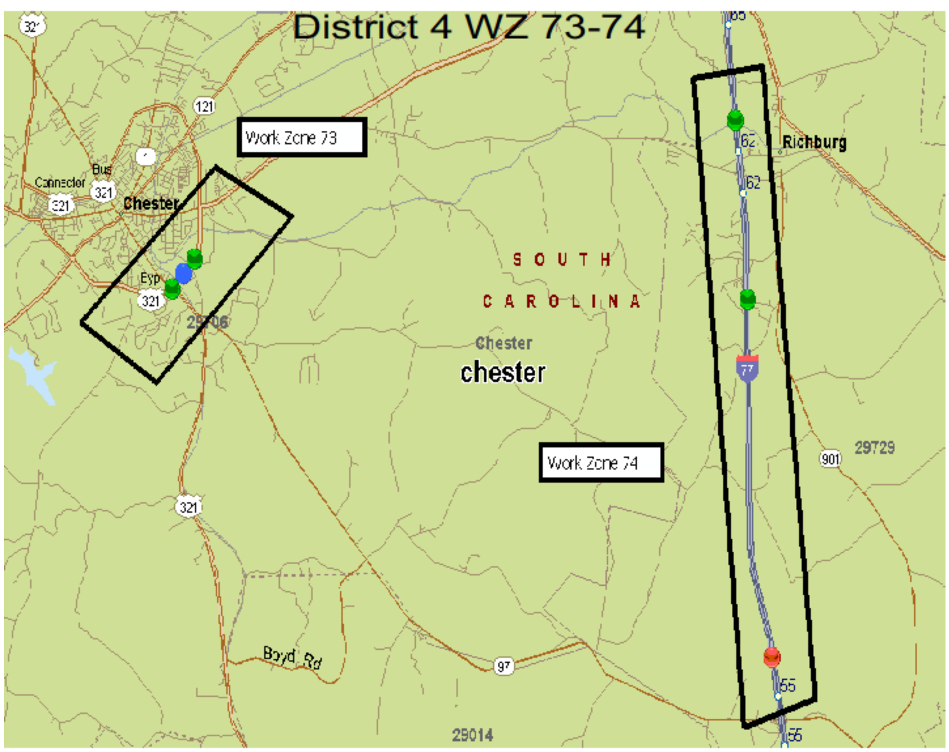


Figure 9-42: District 4 Work Zones 73-74

District 4 WZ 75

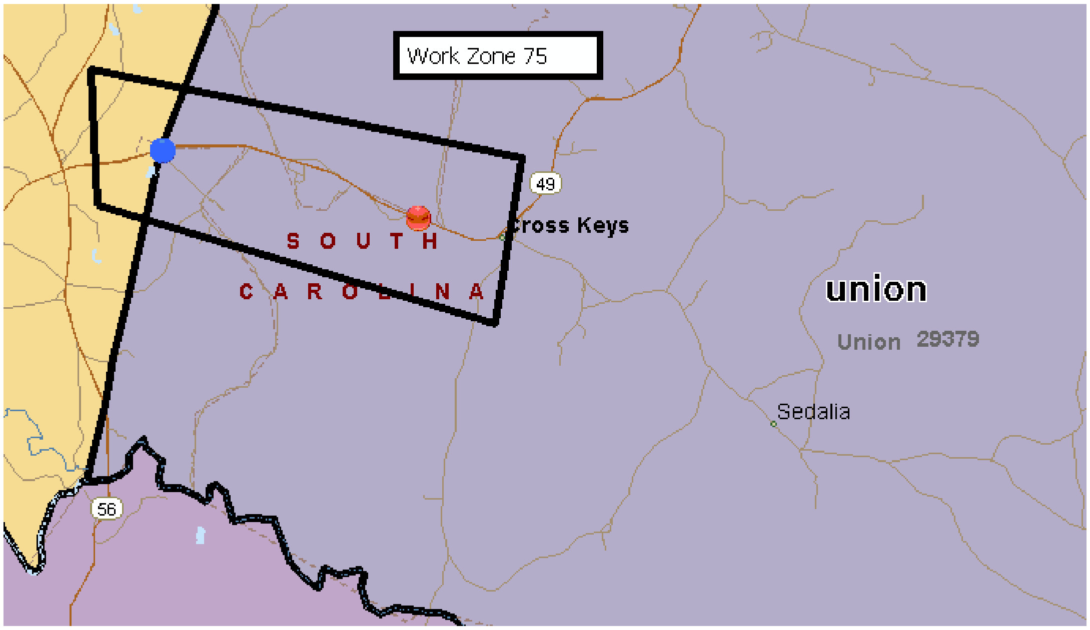


Figure 9-43: District 4 Work Zone 75

District 4 WZ 76

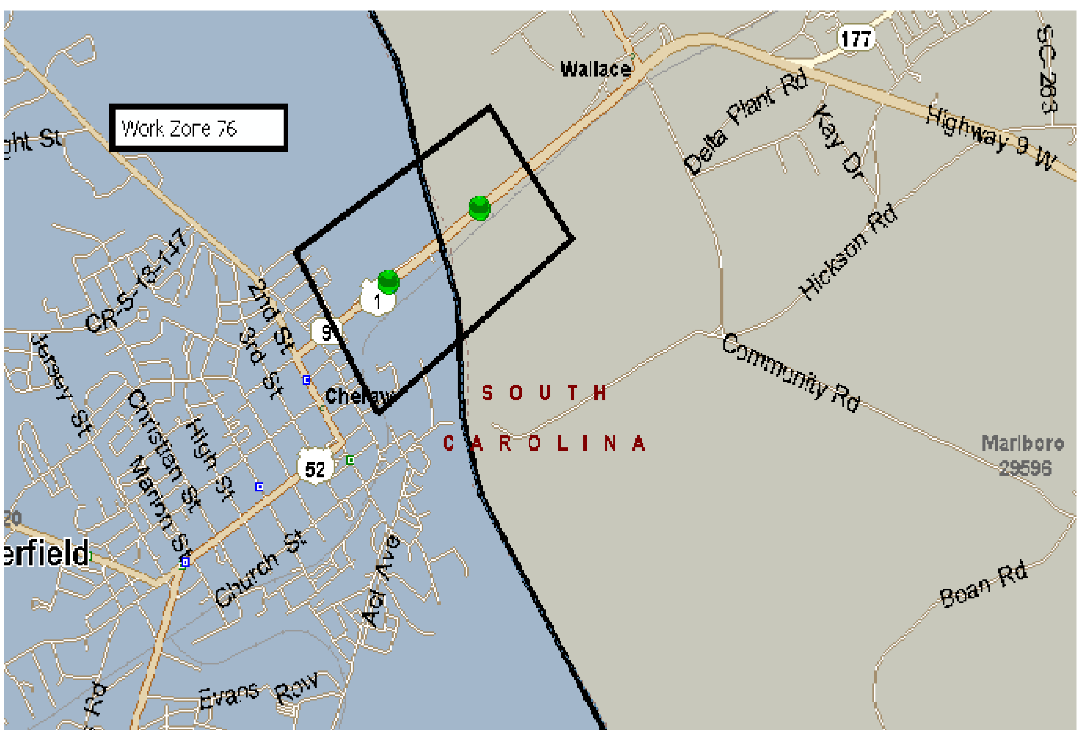


Figure 9-44: District 4 Work Zone 76

9.1.5 District 5 Work Zone Traffic Accident Maps

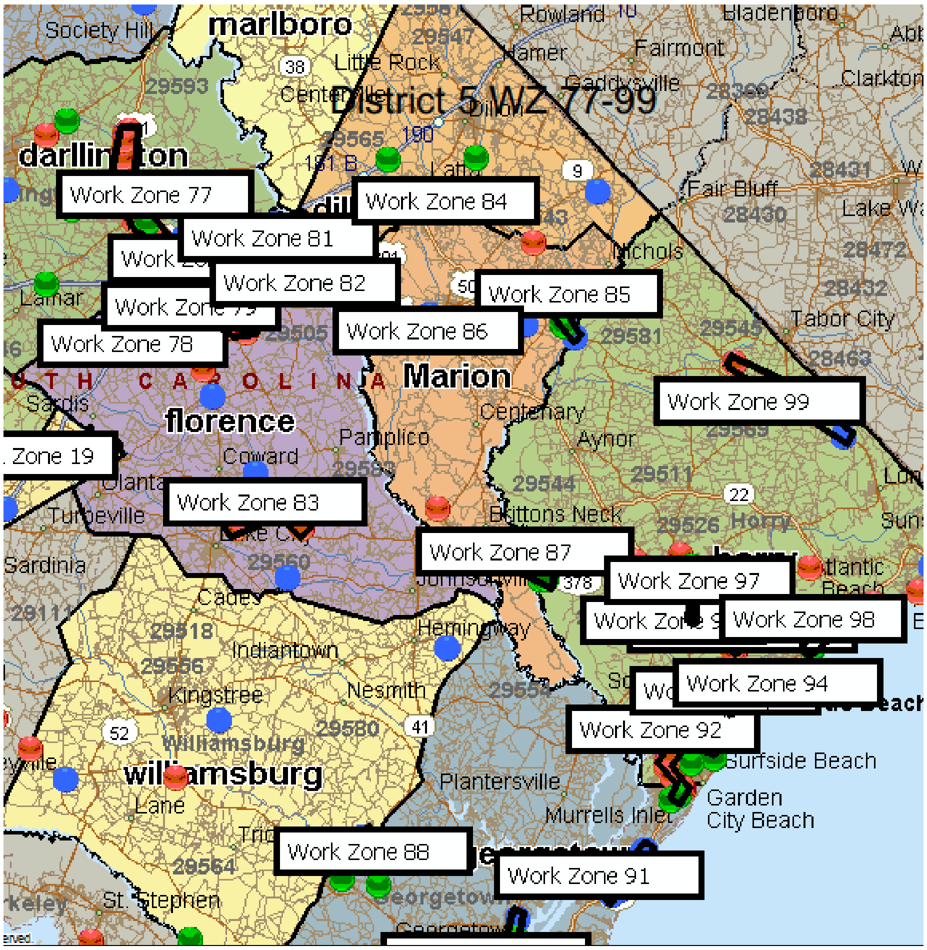


Figure 9-45: District 5 – All Work Zones

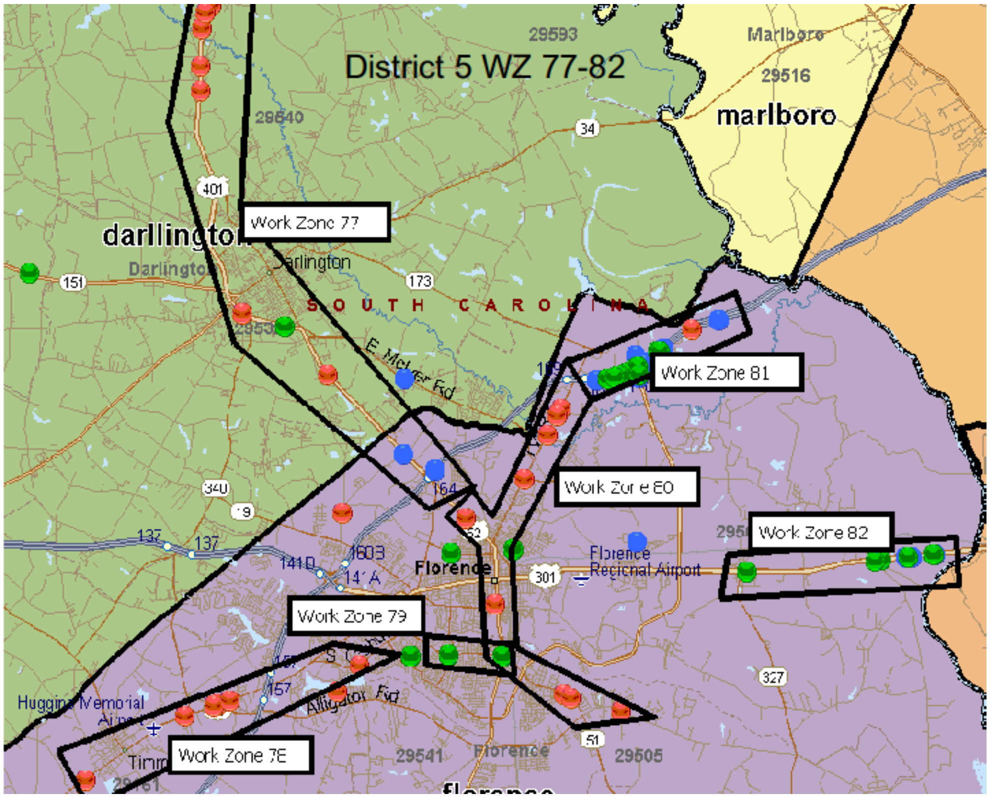


Figure 9-46: District 5 Work Zones 77-82

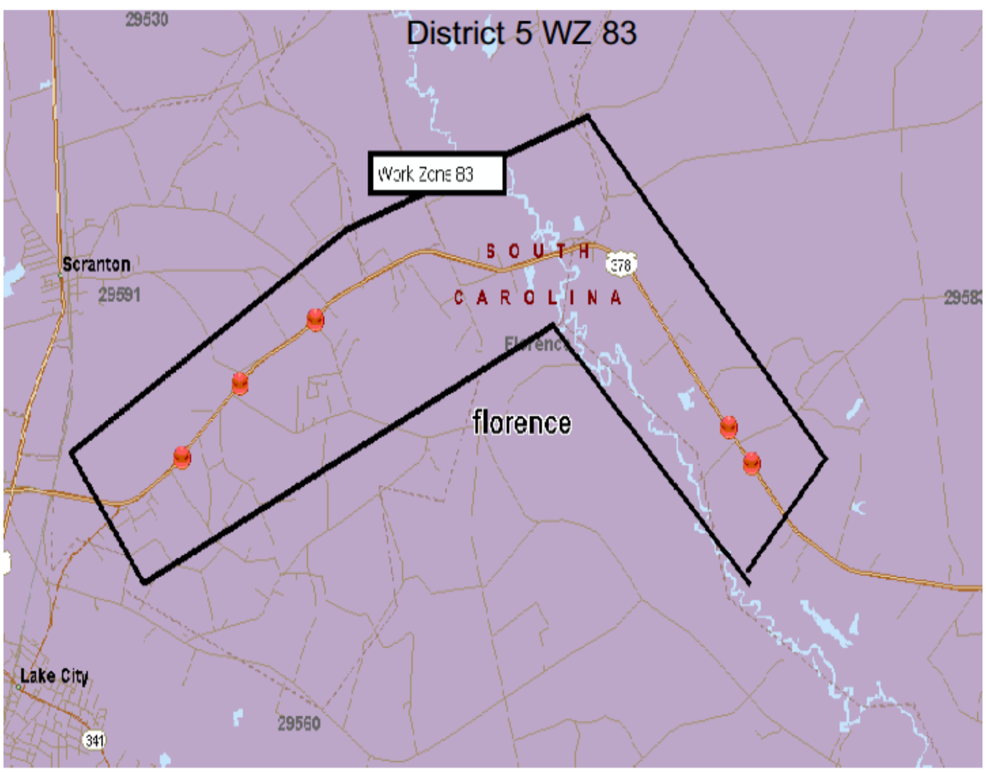


Figure 9-47: District 5 Work Zone 83

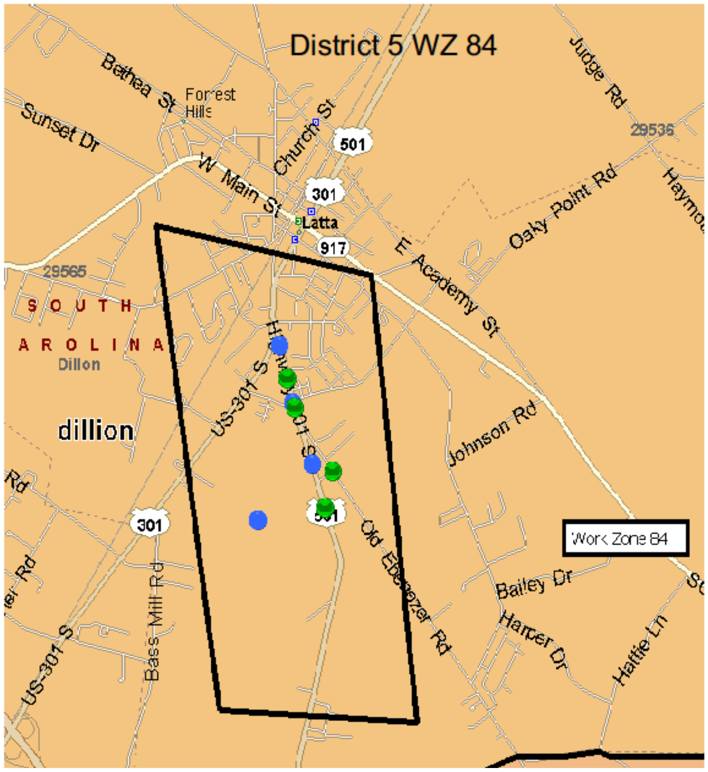


Figure 9-48: District 5 Work Zone 84

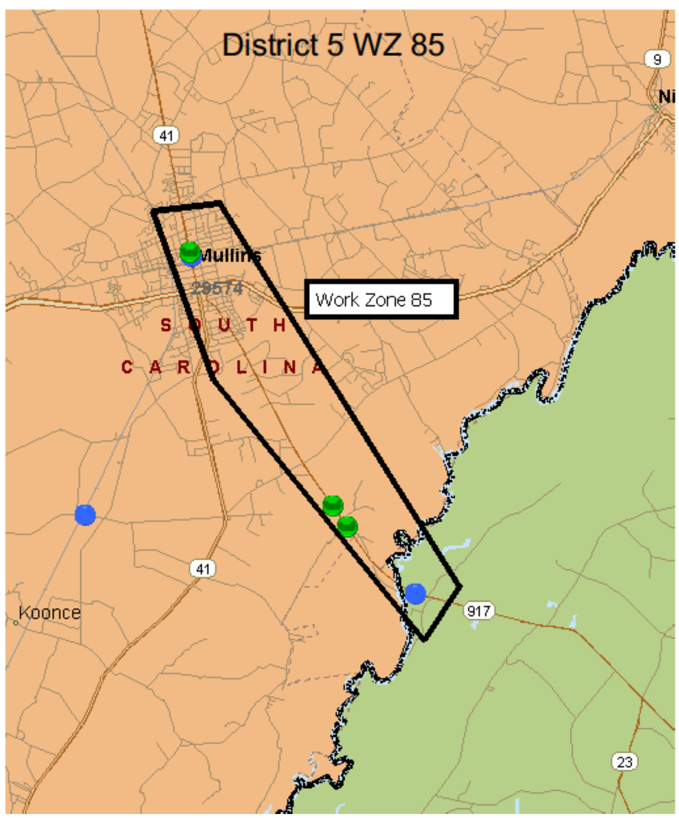


Figure 9-49: District 5 Work Zone 85

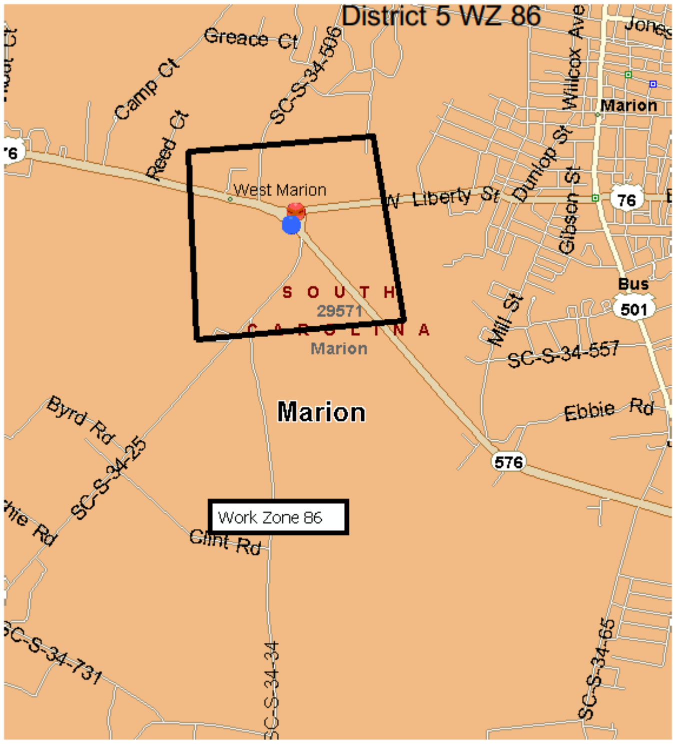


Figure 9-50: District 5 Work Zone 86

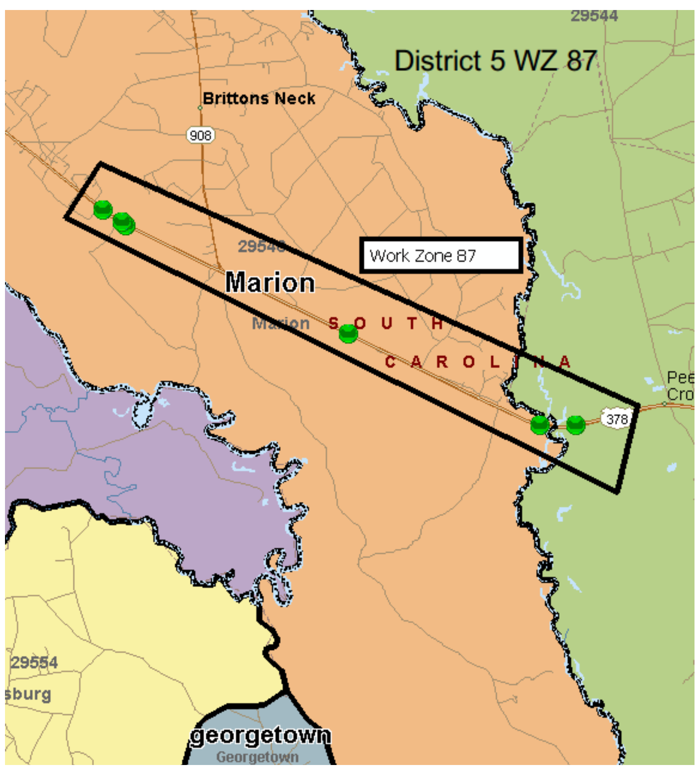


Figure 9-51: District 5 Work Zone 87

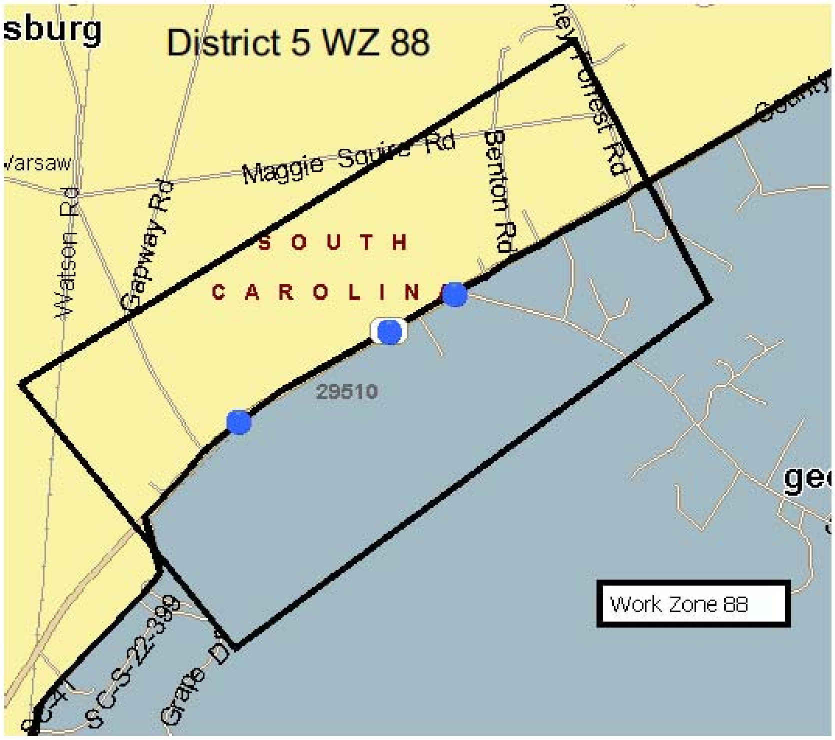


Figure 9-52: District 5 Work Zone 88

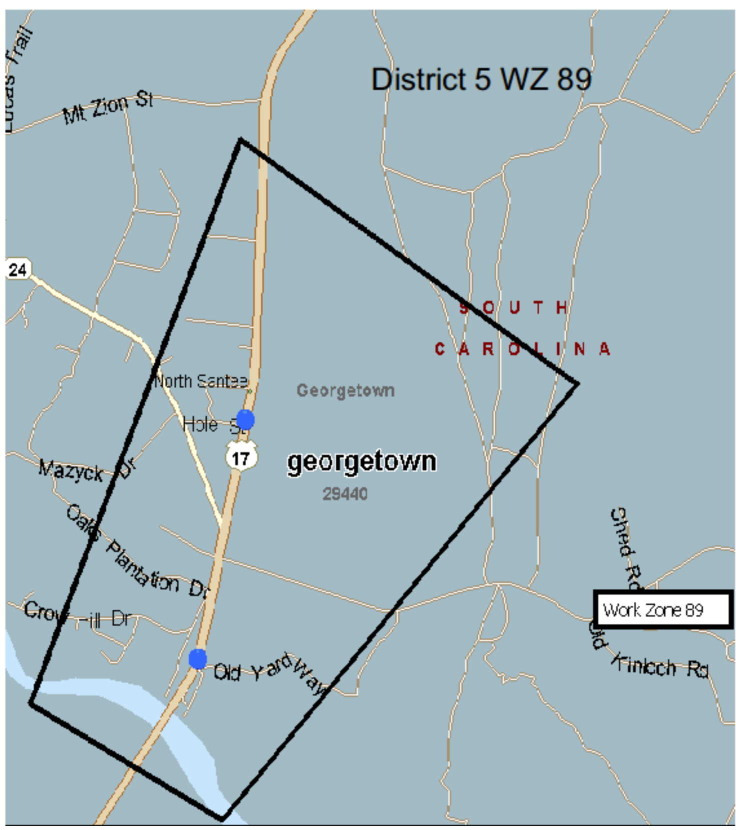


Figure 9-53: District 5 Work Zone 89

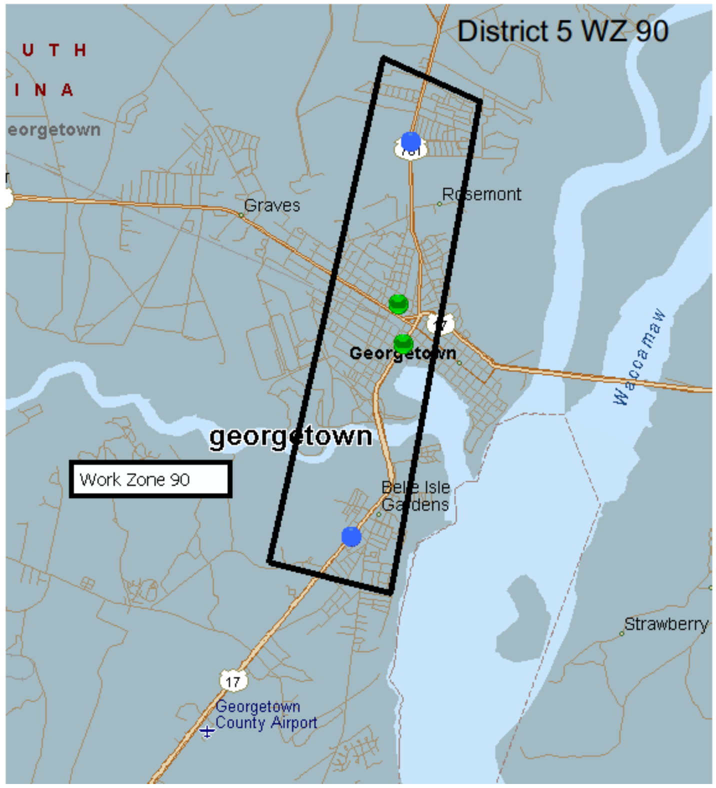


Figure 9-54: District 5 Work Zone 90

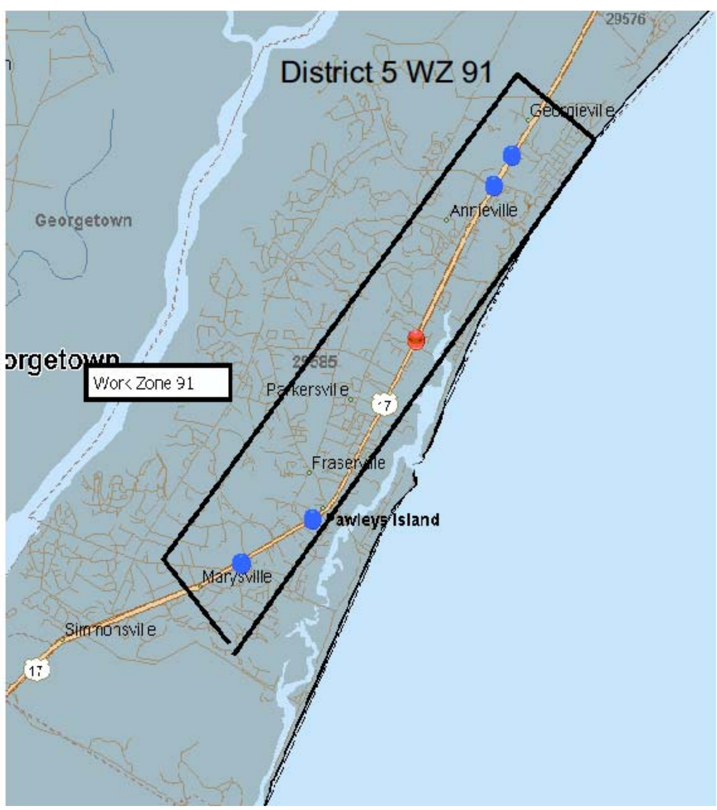


Figure 9-55: District 5 Work Zone 91

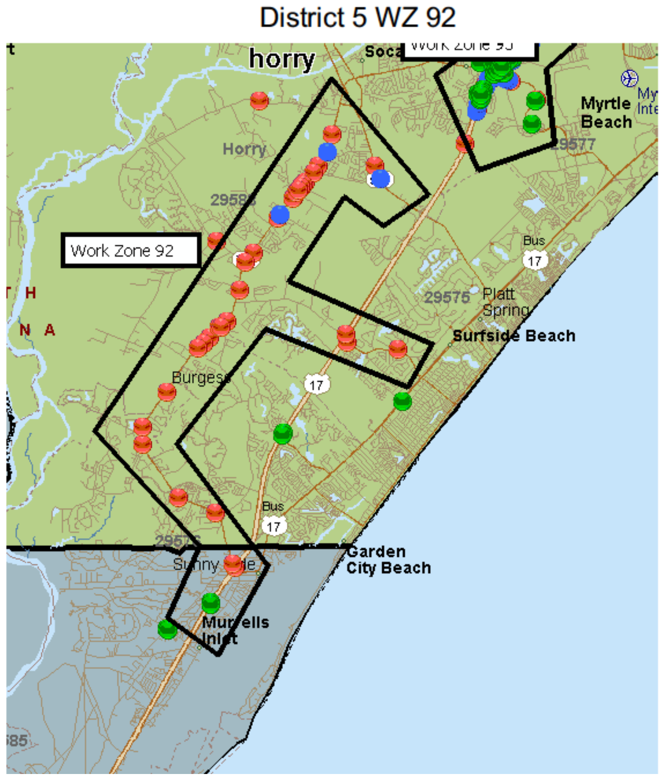


Figure 9-56: District 5 Work Zone 92

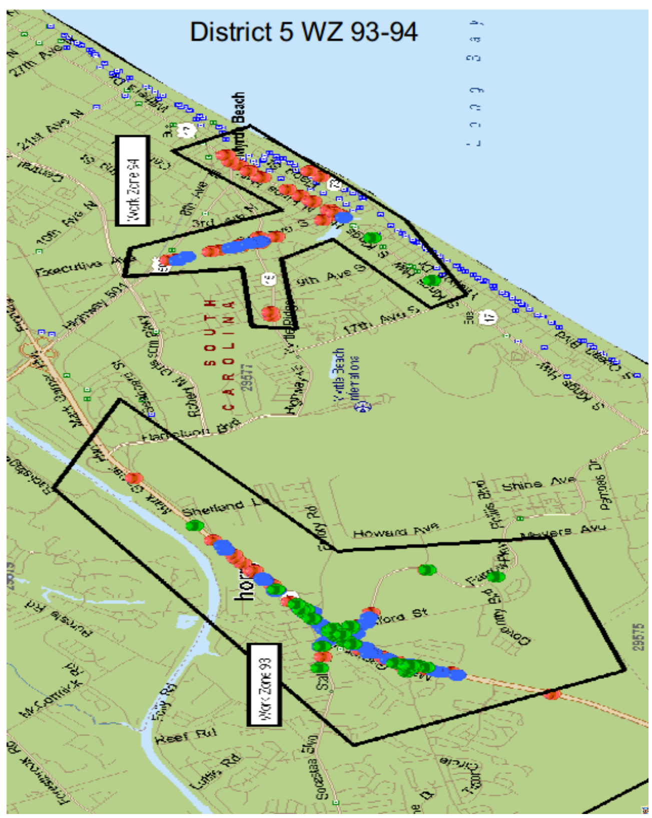


Figure 9-57: District 5 Work Zones 93-94

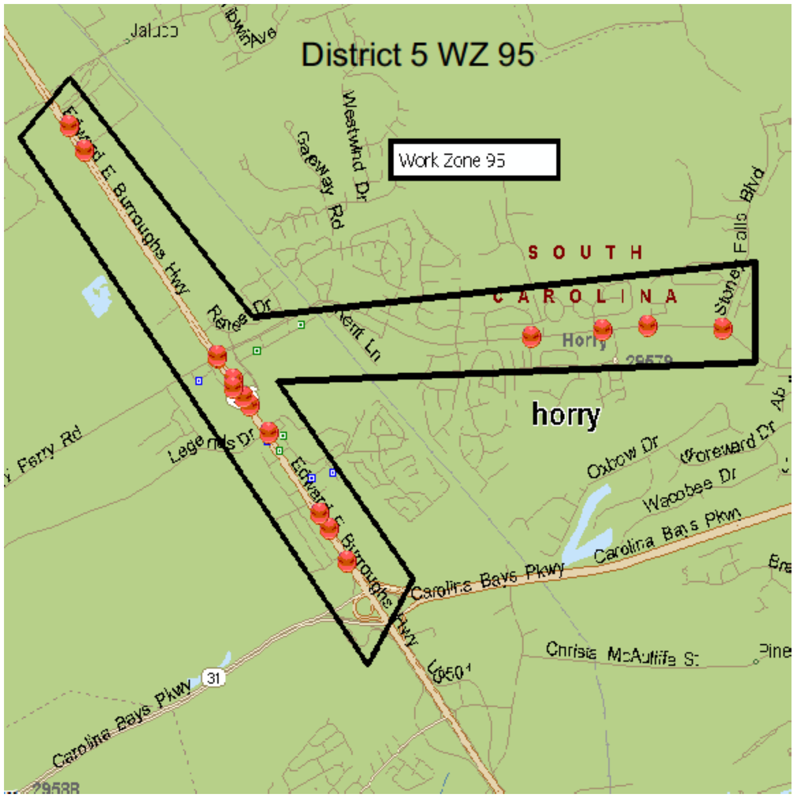


Figure 9-58: District 5 Work Zone 95

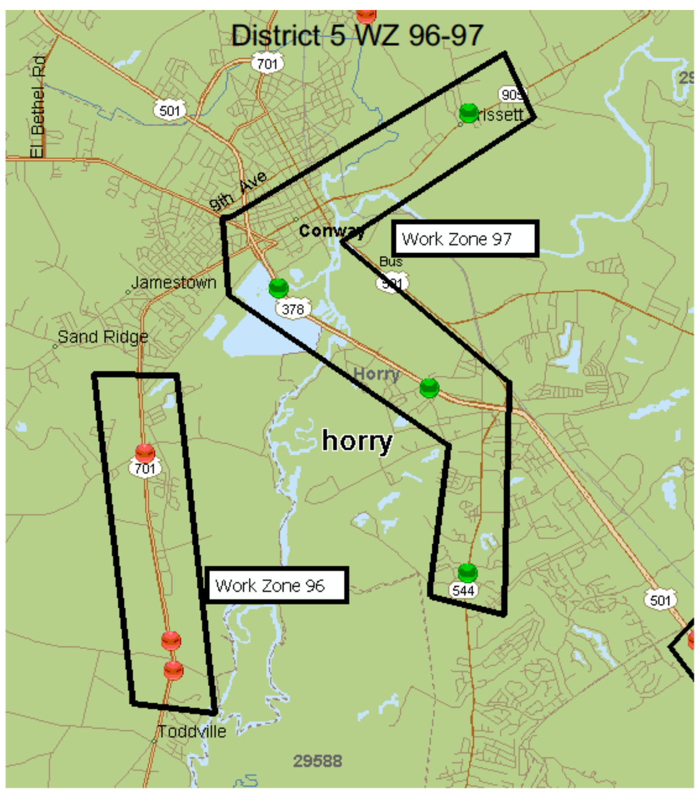


Figure 9-59: District 5 Work Zones 96-97

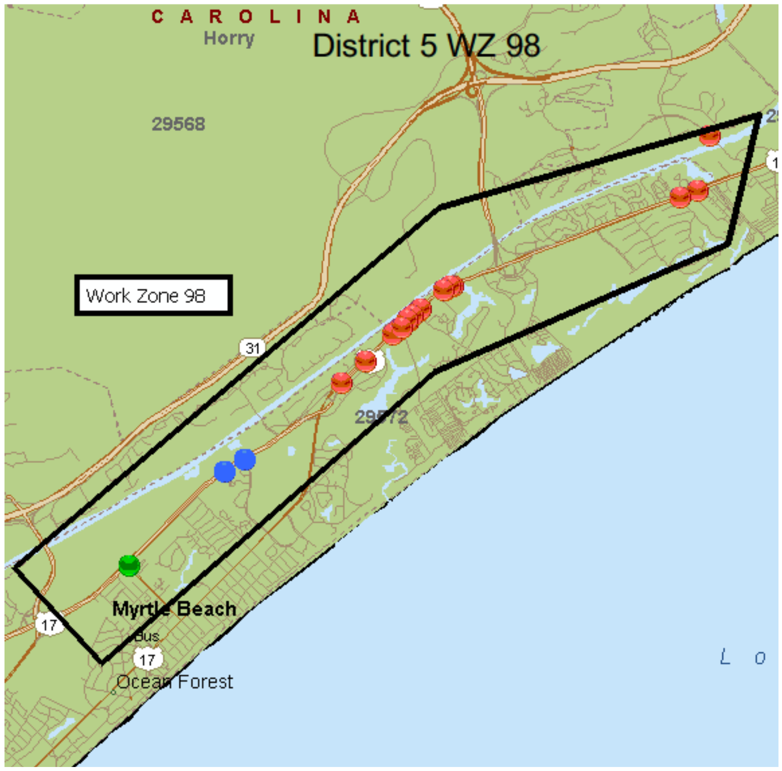


Figure 9-60: District 5 Work Zone 98

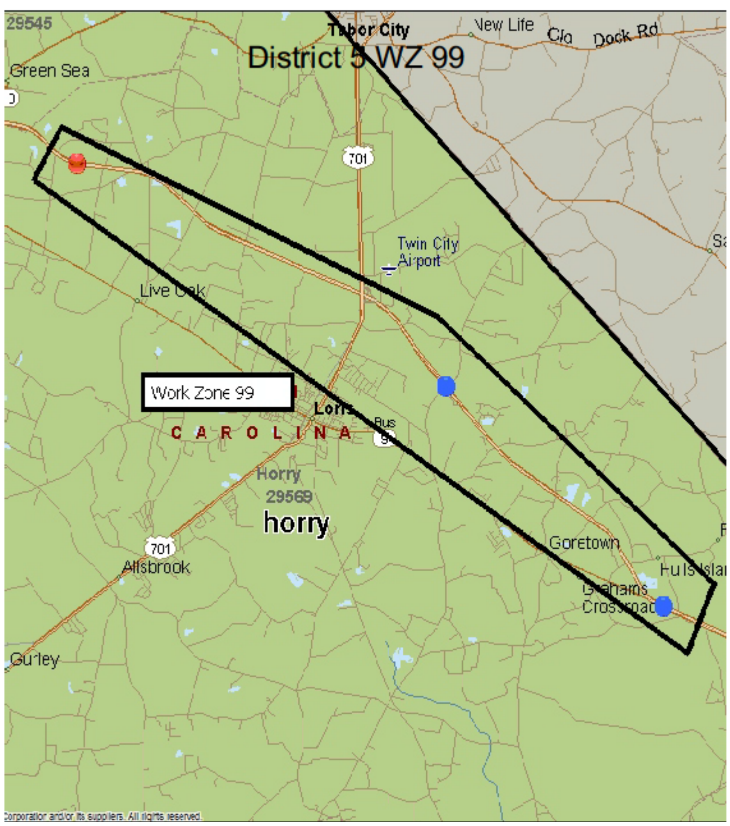


Figure 9-61: District 5 Work Zone 99

9.1.6 District 6 Work Zone Traffic Accident Maps

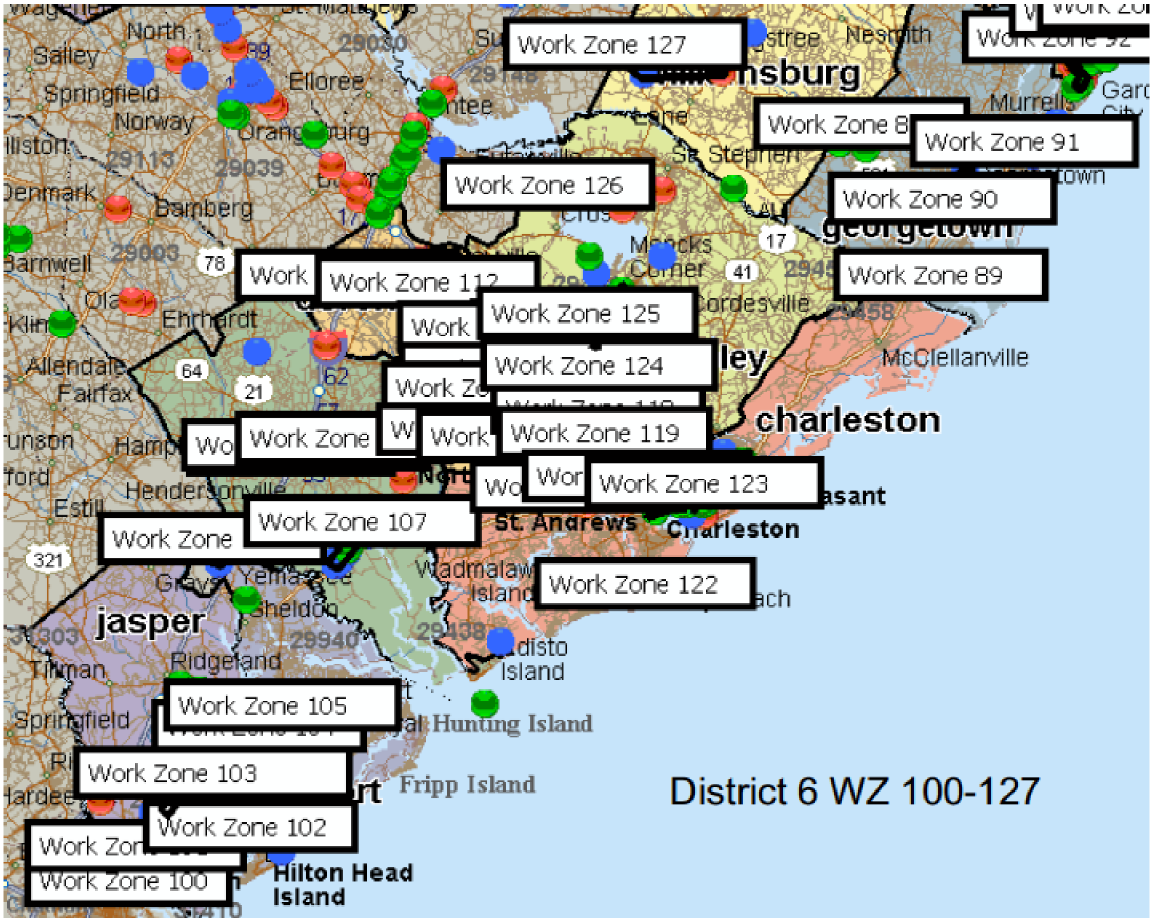


Figure 9-62: District 6 – All Work Zones

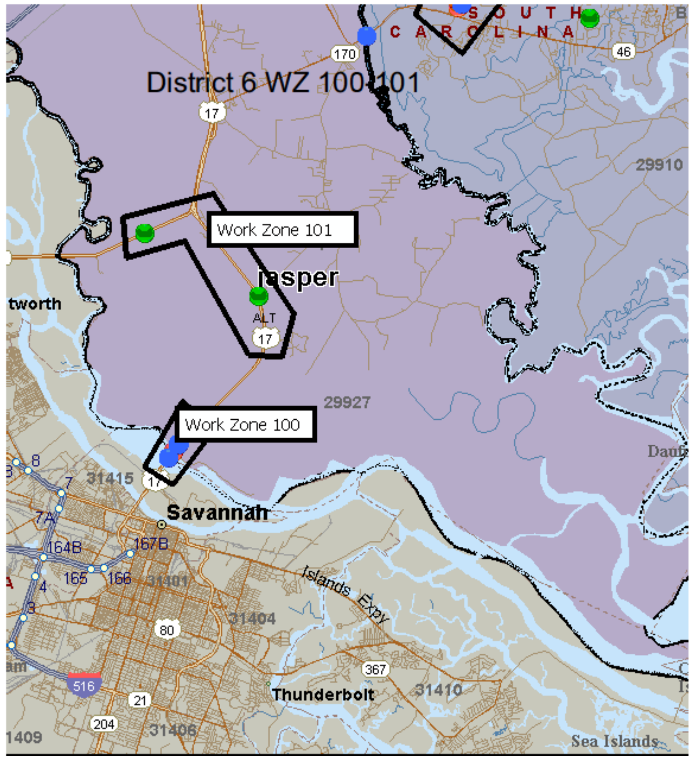


Figure 9-63: District 6 Work Zones 100-101

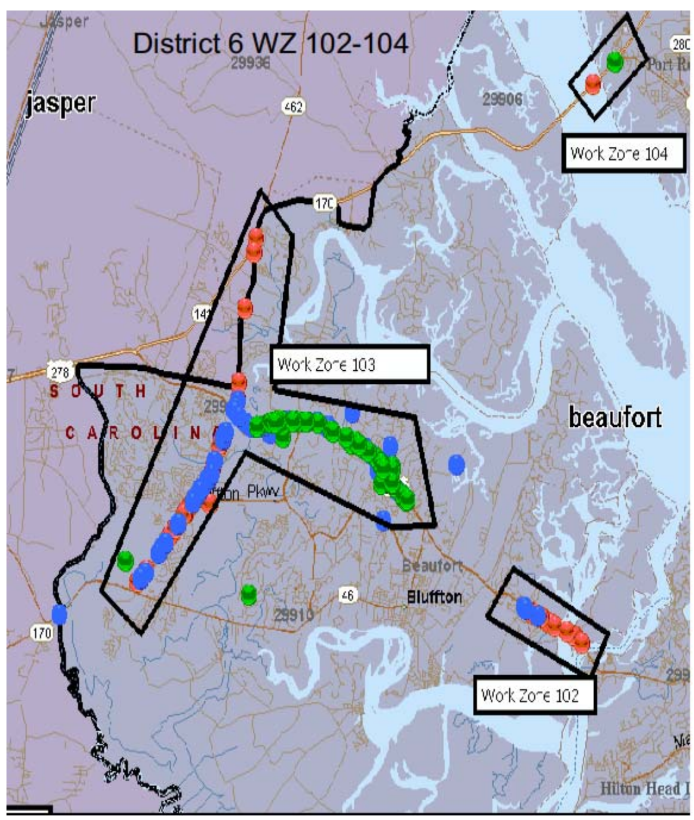


Figure 9-64: District 6 Work Zones 102-104

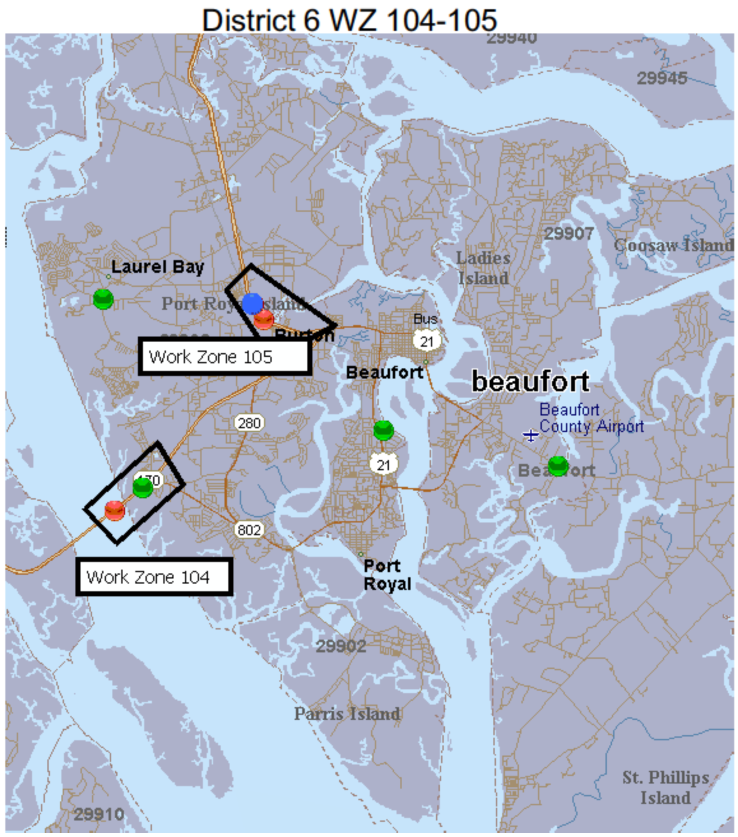


Figure 9-65: District 6 Work Zones 104-105

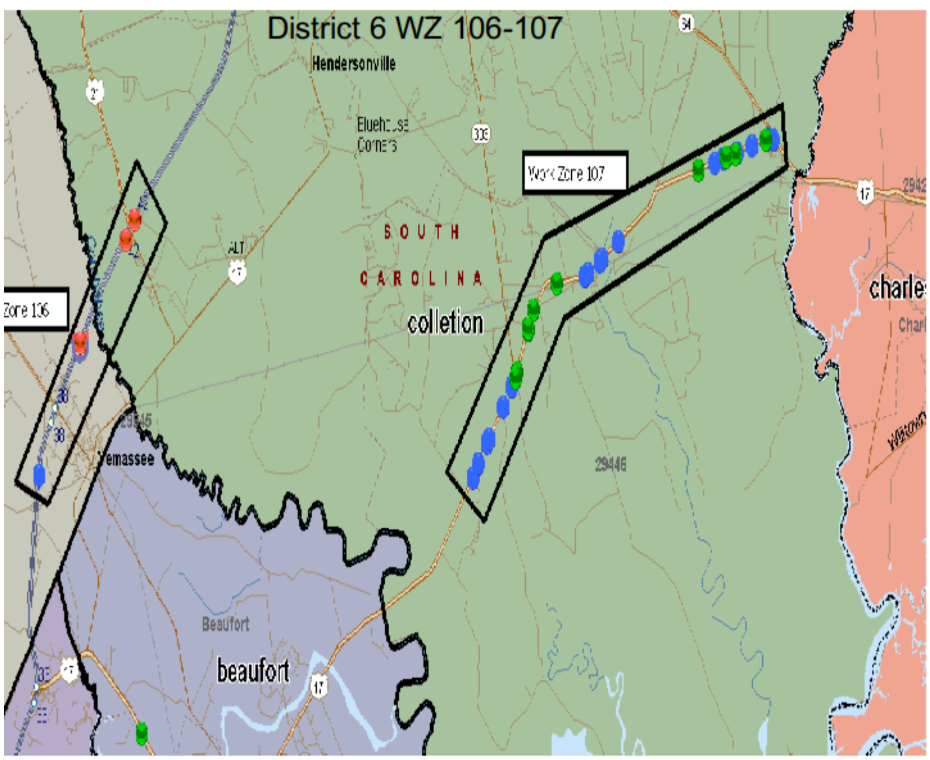


Figure 9-66: District 6 Work Zones 106-107

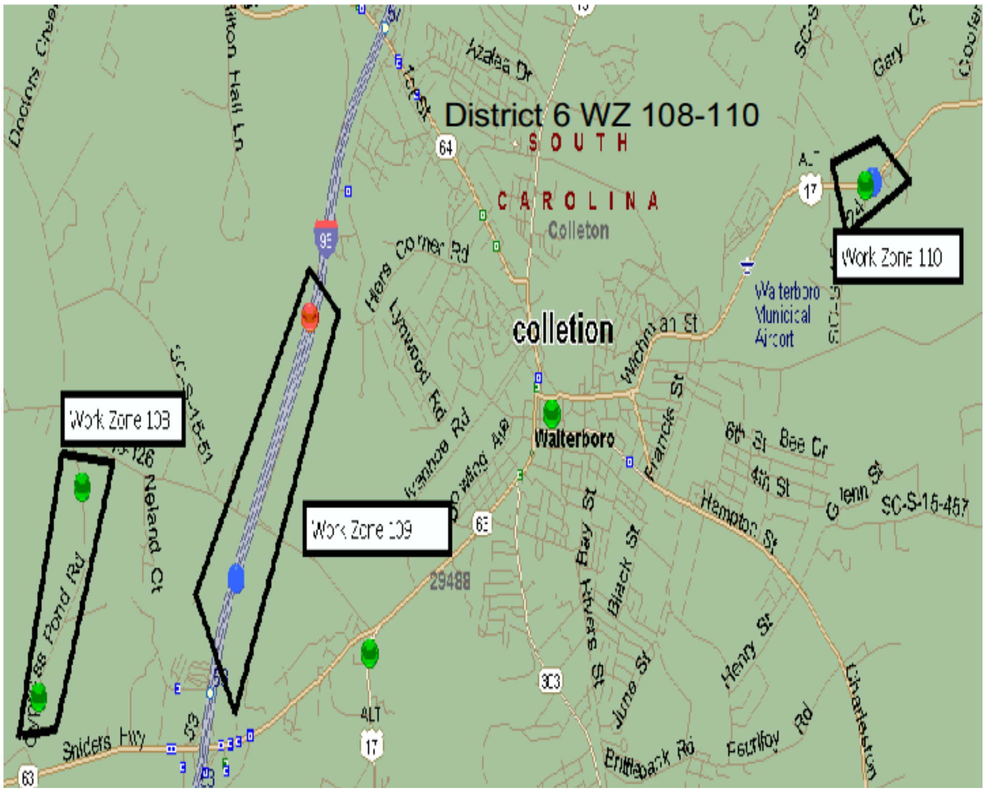


Figure 9-67: District 6 Work Zones 108-110

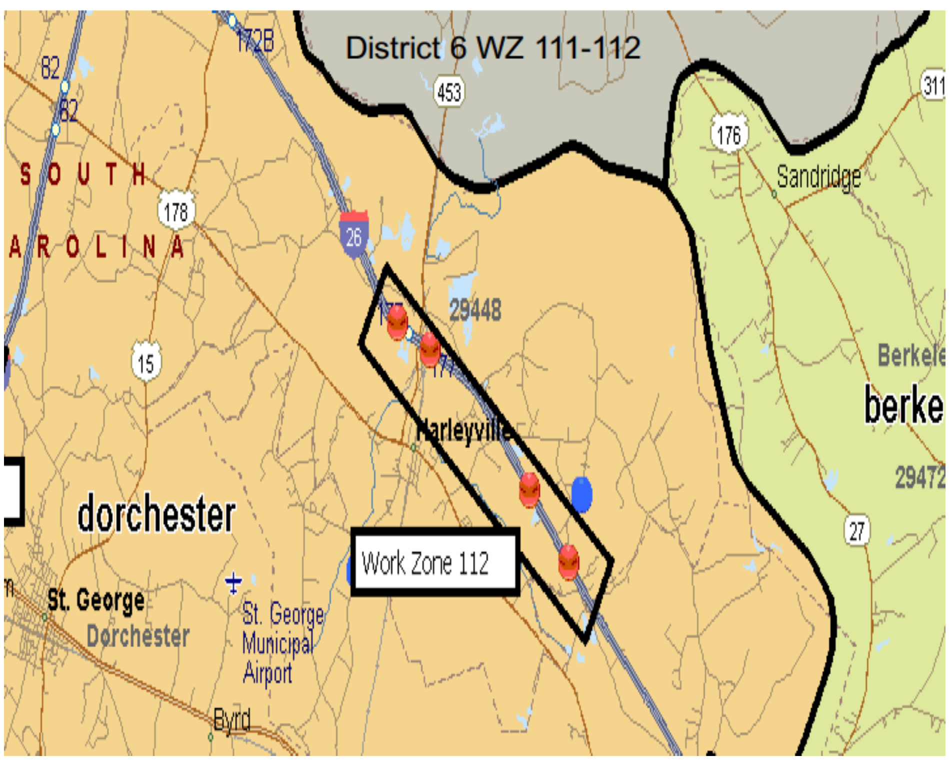


Figure 9-68: District 6 Work Zones 111-112

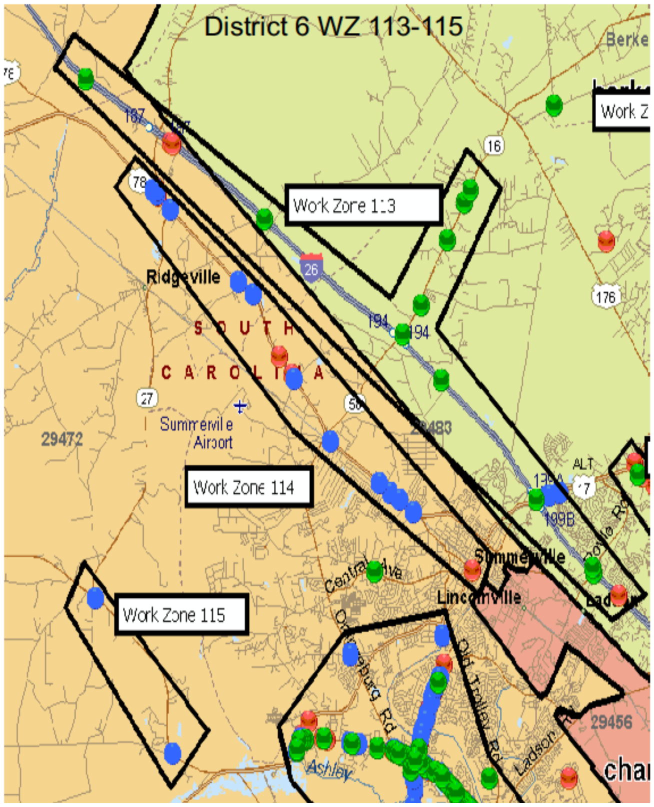


Figure 9-69: District 6 Work Zones 113-115

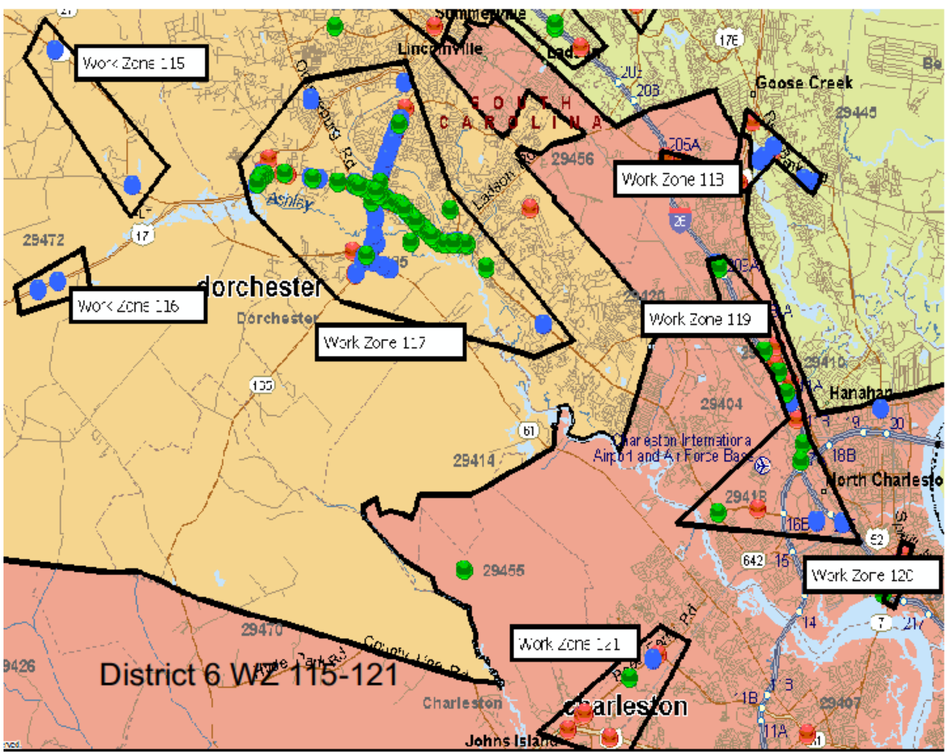


Figure 9-70: District 6 Work Zones 115-121

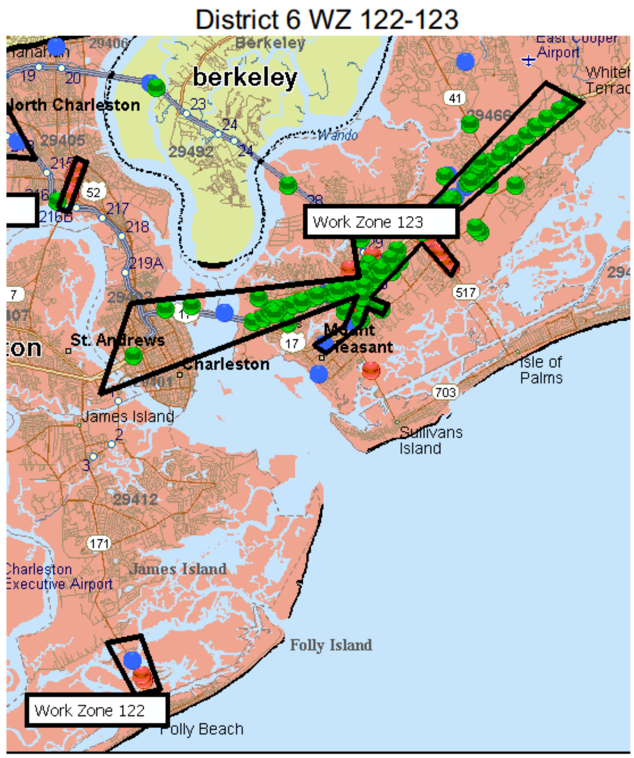


Figure 9-71: District 6 Work Zones 122-123

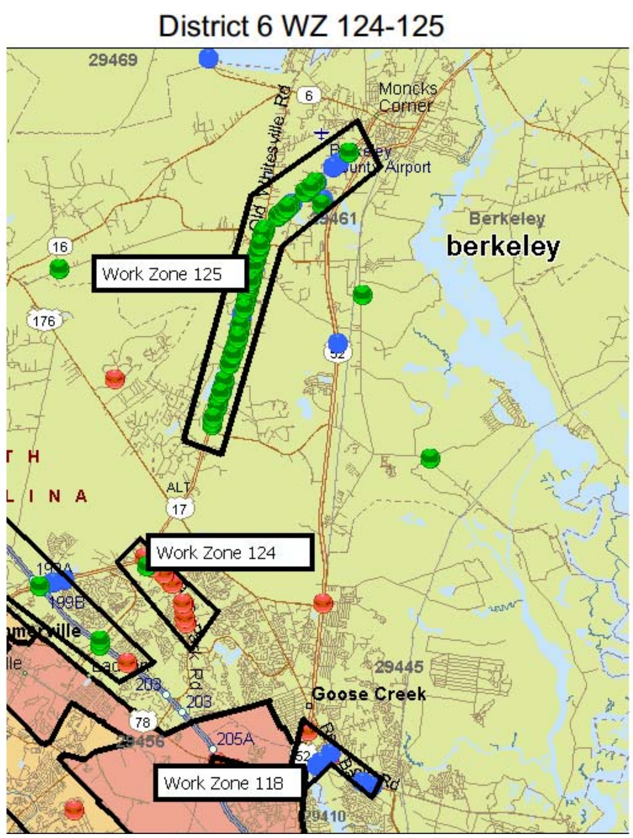


Figure 9-72: District 6 Work Zones 124-125

Figure 9-73: District 6 Work Zone 126

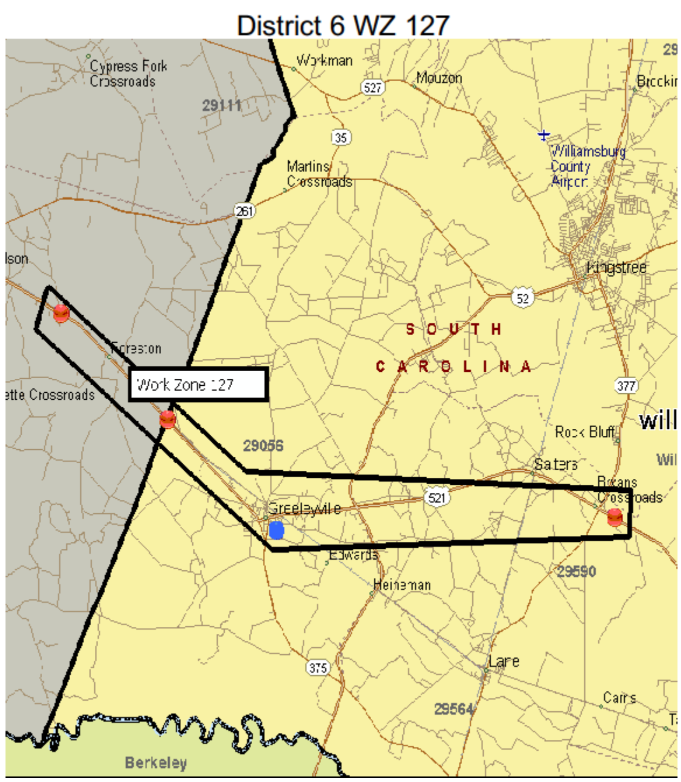


Figure 9-74: District 6 Work Zone 127

9.1.7 District 7 Work Zone Traffic Accident Maps

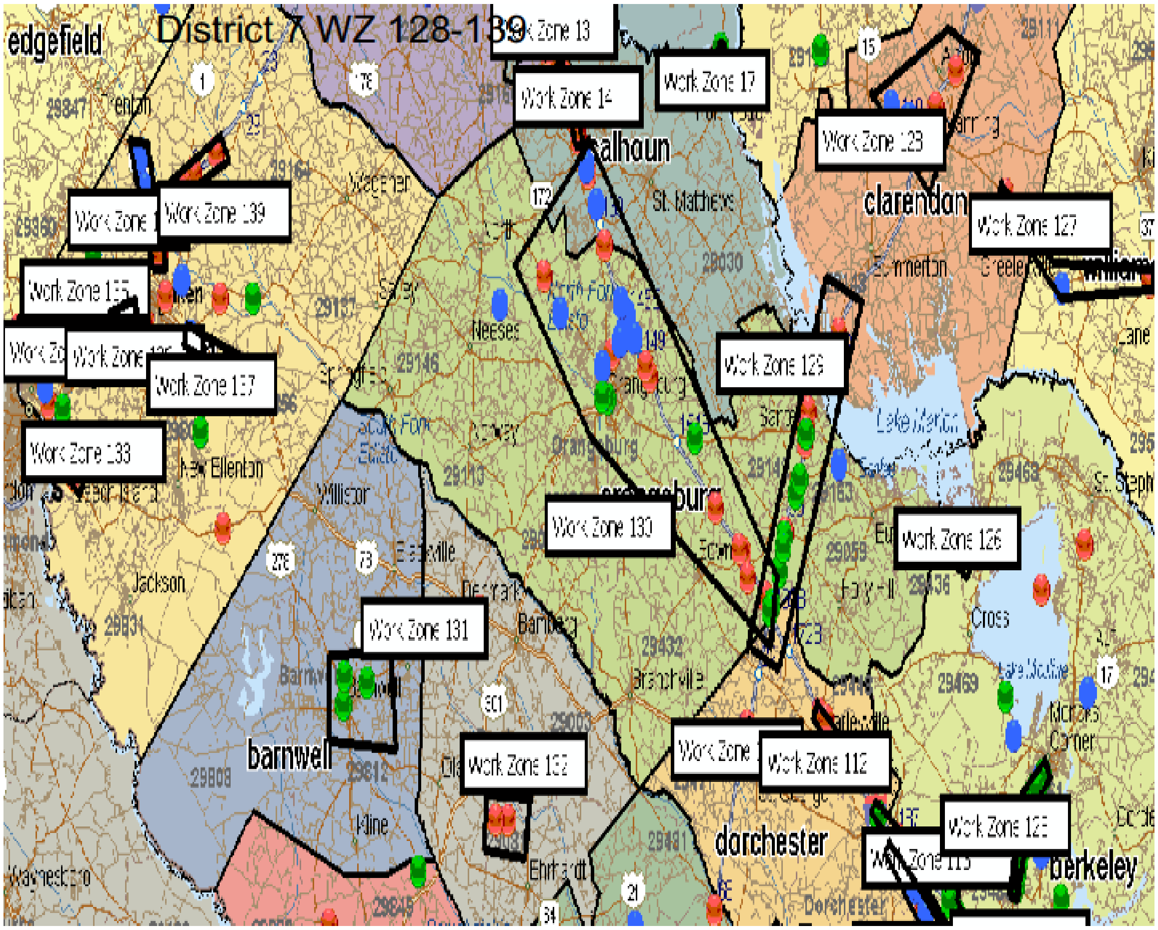


Figure 9-75: District 7 – All Work Zones

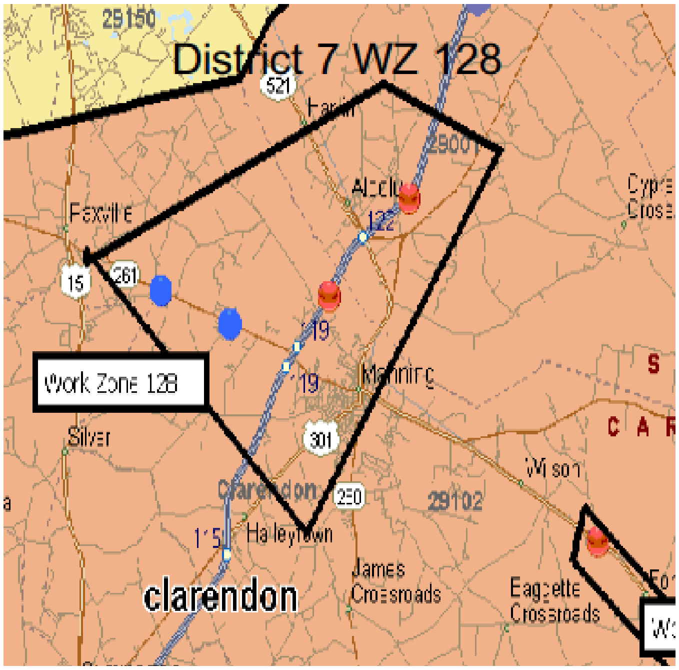


Figure 9-76: District 7 Work Zone 128

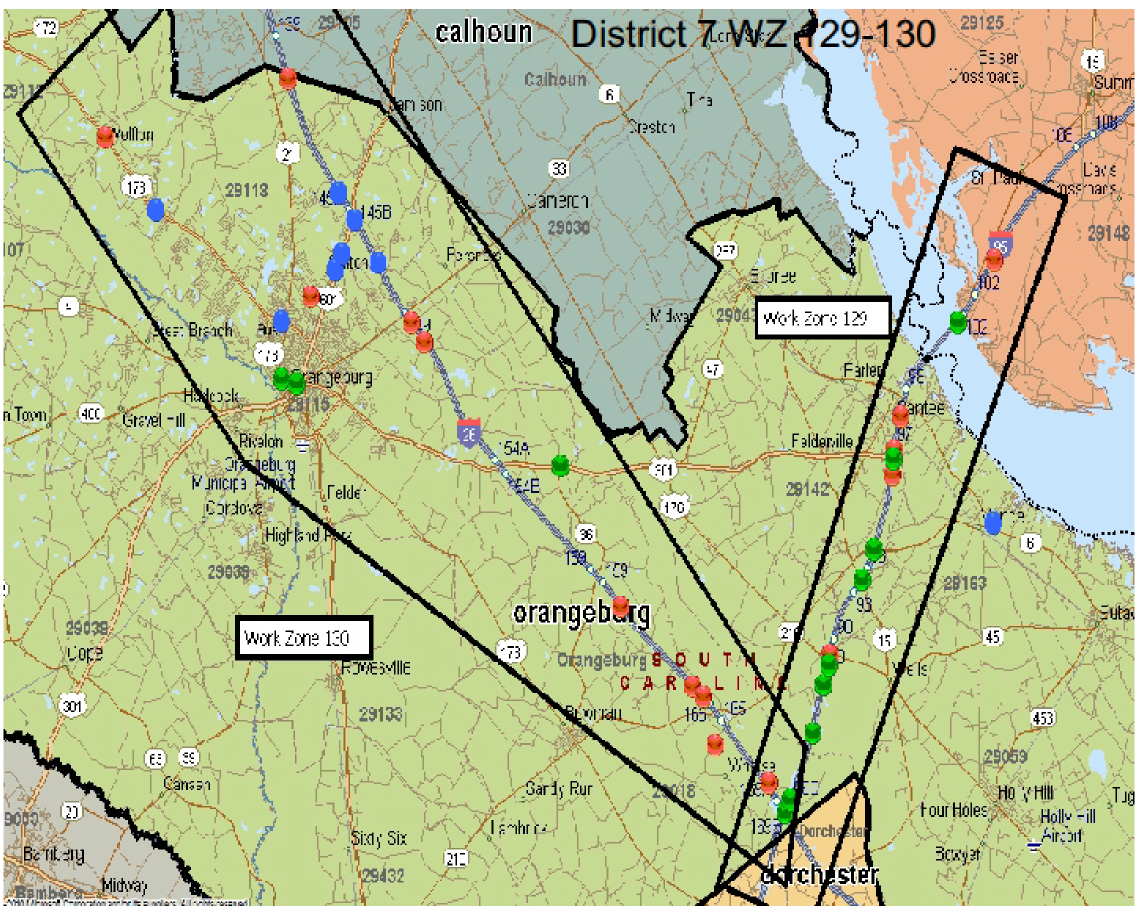


Figure 9-77: District 7 Work Zones 129-130

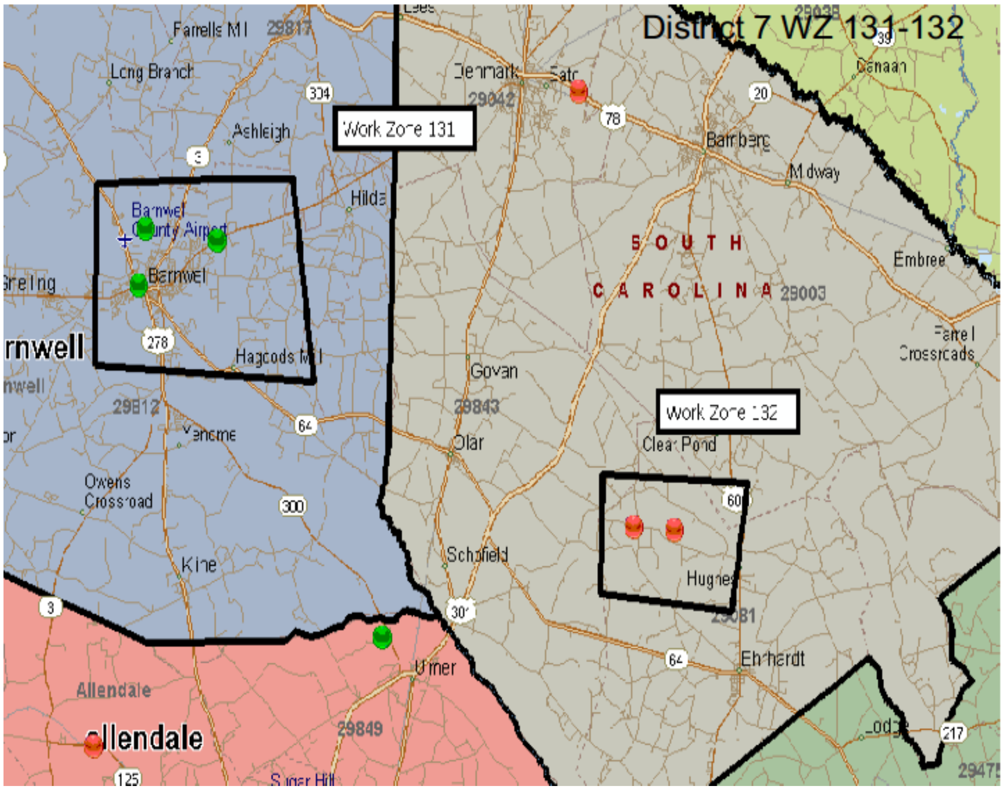


Figure 9-78: District 7 Work Zones 131-132

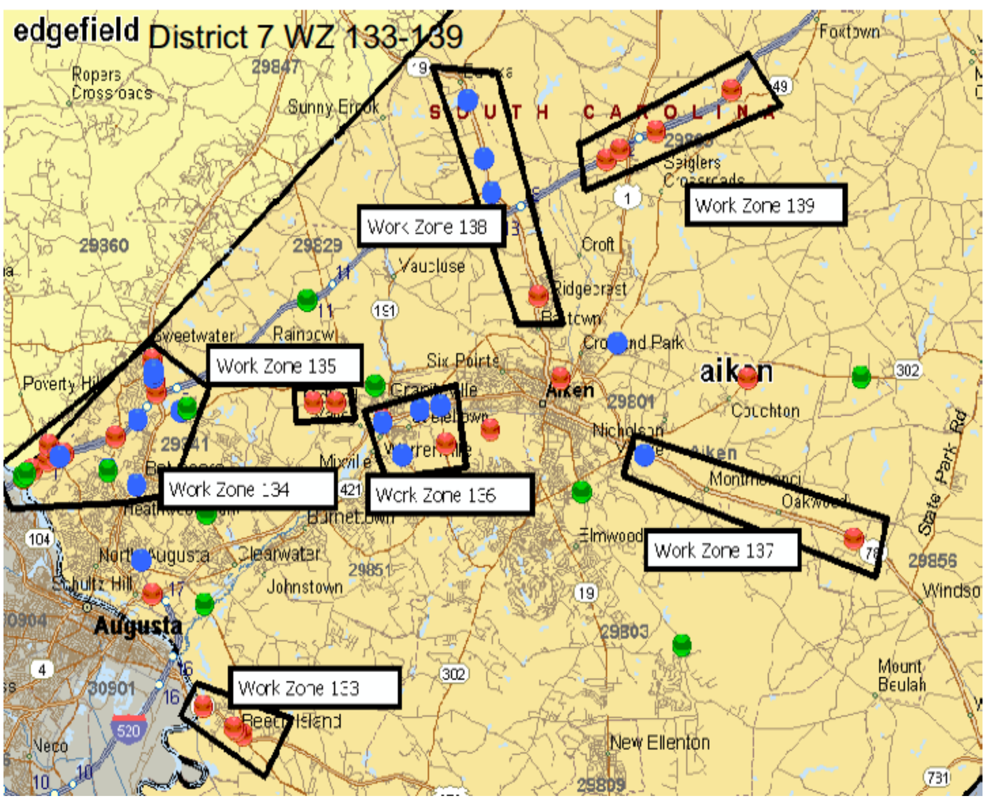
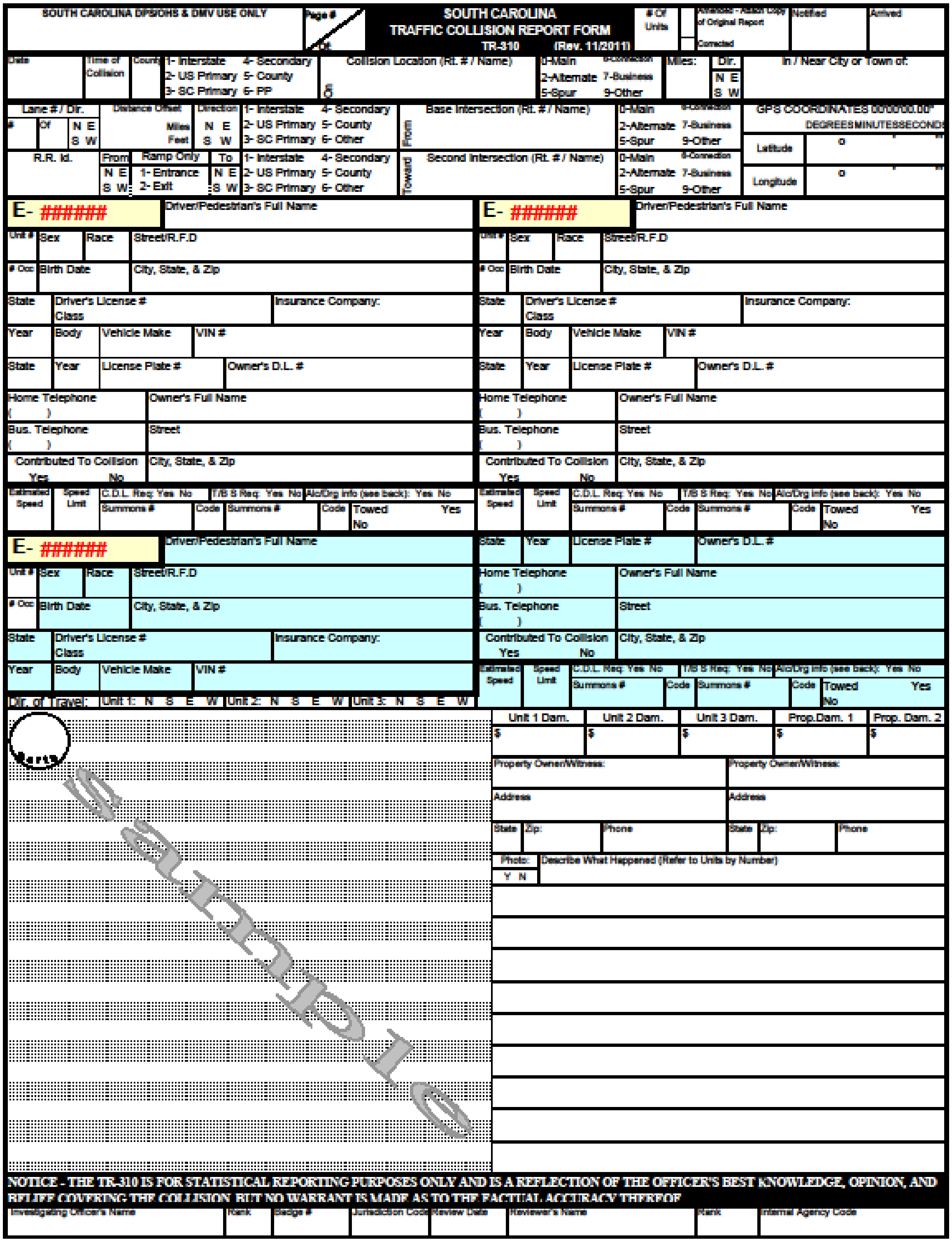


Figure 9-79: District 7 Work Zones 133-139

10 Appendix D

10.1 South Carolina Traffic Collision Report Form TR-310



SOUTH CAROLINA DPS/OHS & DMV USE ONLY
Page # Of
SOUTH CAROLINA
TRAFFIC COLLISION REPORT FORM
TR-310 (Rev. 11/2011)
Of Units
Amended - Attach Copy of Original Report
Corrected
Notified
Arrived

Date | Time of Collision | County | 1- Interstate 4- Secondary 2- US Primary 5- County 3- SC Primary 6- PP | Collision Location (Rt. # / Name) On | 0-Main 8-Connector 2-Alternate 7-Business 5-Spur 9-Other | Miles: | Dir. N E S W | In / Near City or Town of:

Lane # / Dir. # Of N E S W | Distance Offset Miles Feet | Direction N E S W | 1- Interstate 4- Secondary 2- US Primary 5- County 3- SC Primary 6- Other | From | Base Intersection (Rt. # / Name) | 0-Main 8-Connection 2-Alternate 7-Business 5-Spur 9-Other | GPS COORDINATES 00°00'00.00" DEGREESMINUTESSECONDS

R.R. Id. | From N E S W | Ramp Only 1- Entrance 2- Exit | To N E S W | 1- Interstate 4- Secondary 2- US Primary 5- County 3- SC Primary 6- Other | Toward | Second Intersection (Rt. # / Name) | 0-Main 8-Connection 2-Alternate 7-Business 5-Spur 9-Other | Latitude ° ' " | Longitude ° ' "

E- ###### Driver/Pedestrian's Full Name
Unit # | Sex | Race | Street/R.F.D
Occ | Birth Date | City, State, & Zip
State | Driver's License # Class | Insurance Company:
Year | Body | Vehicle Make | VIN #
State | Year | License Plate # | Owner's D.L. #
Home Telephone ( ) | Owner's Full Name
Bus. Telephone ( ) | Street
Contributed To Collision Yes No | City, State, & Zip
Estimated Speed | Speed Limit | C.D.L. Req: Yes No | T/B S Req: Yes No | Alc/Drg info (see back): Yes No
Summons # | Code | Summons # | Code | Towed Yes No

E- ###### Driver/Pedestrian's Full Name
Unit # | Sex | Race | Street/R.F.D
Occ | Birth Date | City, State, & Zip
State | Driver's License # Class | Insurance Company:
Year | Body | Vehicle Make | VIN #
State | Year | License Plate # | Owner's D.L. #
Home Telephone ( ) | Owner's Full Name
Bus. Telephone ( ) | Street
Contributed To Collision Yes No | City, State, & Zip
Estimated Speed | Speed Limit | C.D.L. Req: Yes No | T/B S Req: Yes No | Alc/Drg info (see back): Yes No
Summons # | Code | Summons # | Code | Towed Yes No

E- ###### Driver/Pedestrian's Full Name
Unit # | Sex | Race | Street/R.F.D
Occ | Birth Date | City, State, & Zip
State | Driver's License # Class | Insurance Company:
Year | Body | Vehicle Make | VIN #
State | Year | License Plate # | Owner's D.L. #
Home Telephone ( ) | Owner's Full Name
Bus. Telephone ( ) | Street
Contributed To Collision Yes No | City, State, & Zip
Estimated Speed | Speed Limit | C.D.L. Req: Yes No | T/B S Req: Yes No | Alc/Drg info (see back): Yes No
Summons # | Code | Summons # | Code | Towed Yes No

Dir. of Travel: Unit 1: N S E W Unit 2: N S E W Unit 3: N S E W
North

Unit 1 Dam. $ | Unit 2 Dam. $ | Unit 3 Dam. $ | Prop.Dam. 1 $ | Prop. Dam. 2 $
Property Owner/Witness: | Property Owner/Witness:
Address | Address
State | Zip: | Phone | State | Zip: | Phone
Photo: Y N | Describe What Happened (Refer to Units by Number)

NOTICE - THE TR-310 IS FOR STATISTICAL REPORTING PURPOSES ONLY AND IS A REFLECTION OF THE OFFICER'S BEST KNOWLEDGE, OPINION, AND BELIEF COVERING THE COLLISION, BUT NO WARRANT IS MADE AS TO THE FACTUAL ACCURACY THEREOF.

Investigating Officer's Name | Rank | Badge # | Jurisdiction Code | Review Date | Reviewer's Name | Rank | Internal Agency Code

Figure 10-1: South Carolina Traffic Collision Report Form TR-310, Page 1 of 2

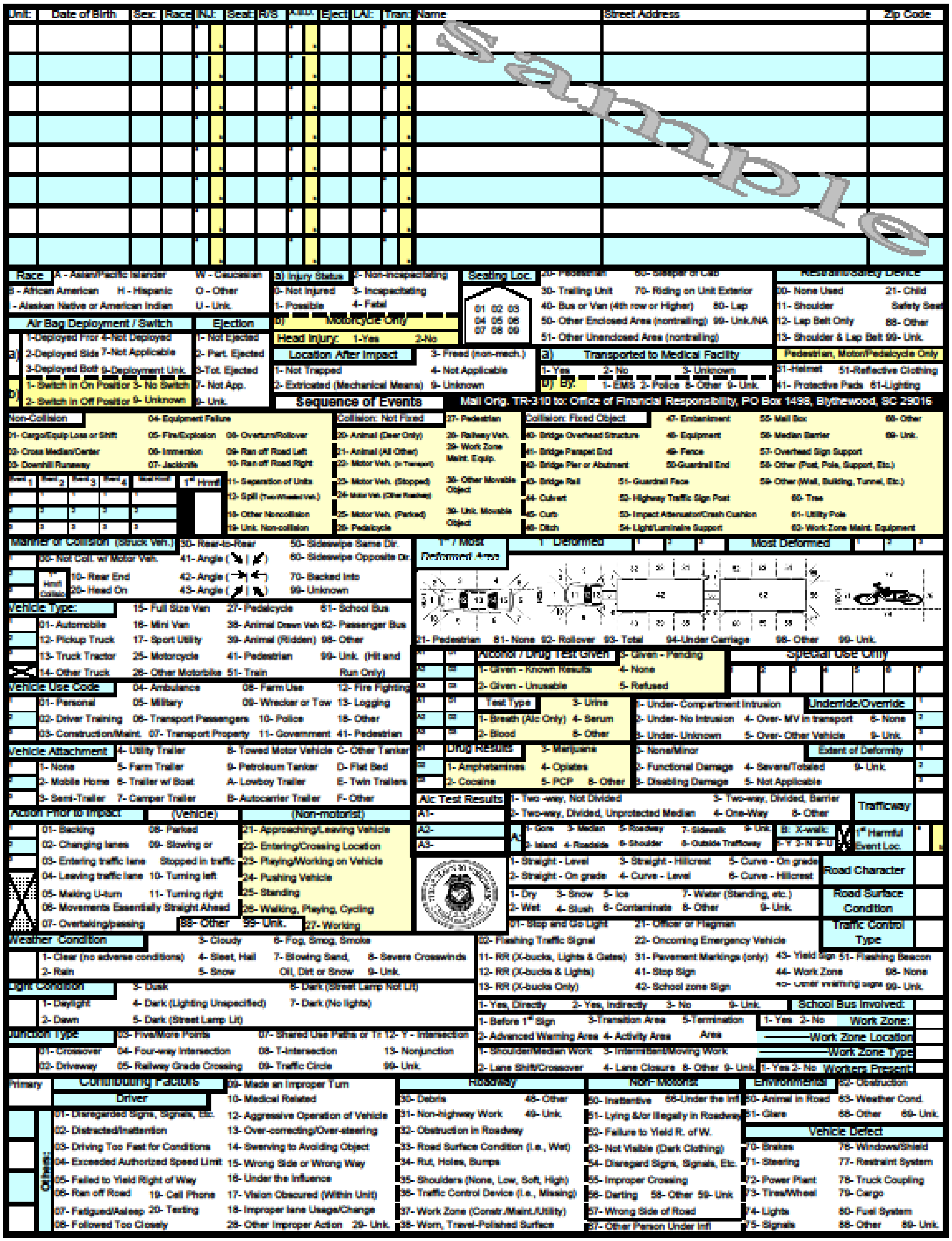


Figure 10-2: South Carolina Traffic Collision Report Form TR-310, Page 2 of 2

11 Appendix E

11.1 Results of the State DOTs Nighttime Paving Survey

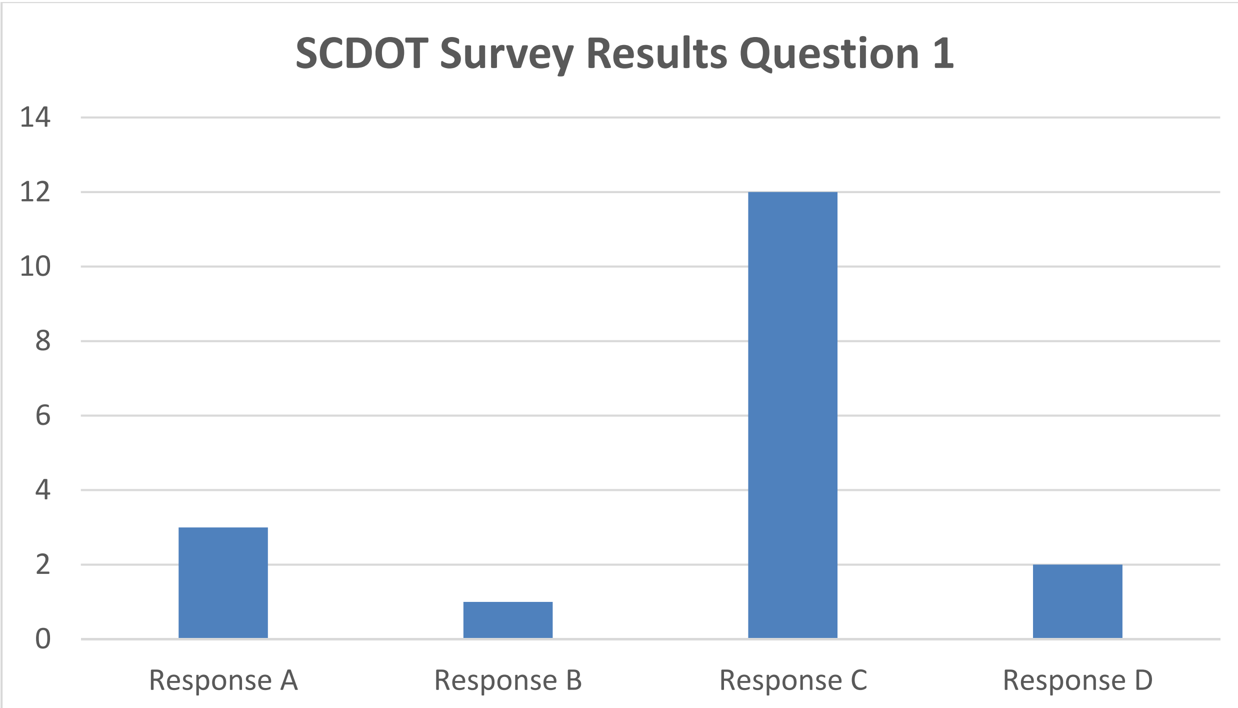


Figure 11-1: Results of SCDOT Nighttime Survey Question 1

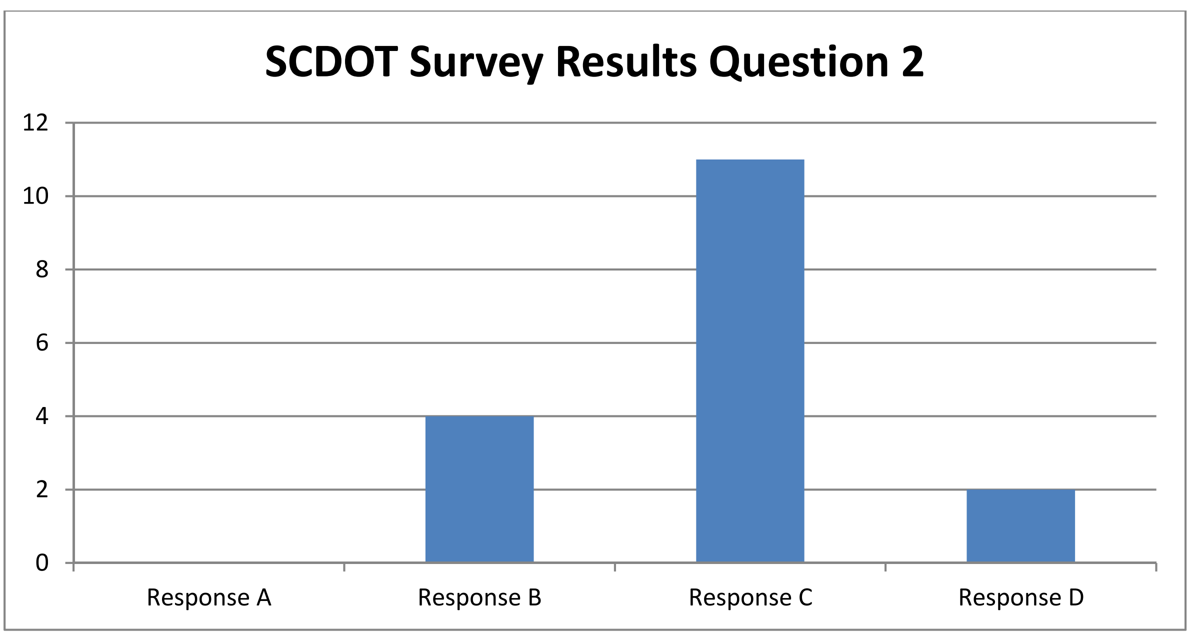


Figure 11-2: Results of SCDOT Nighttime Survey Question 2

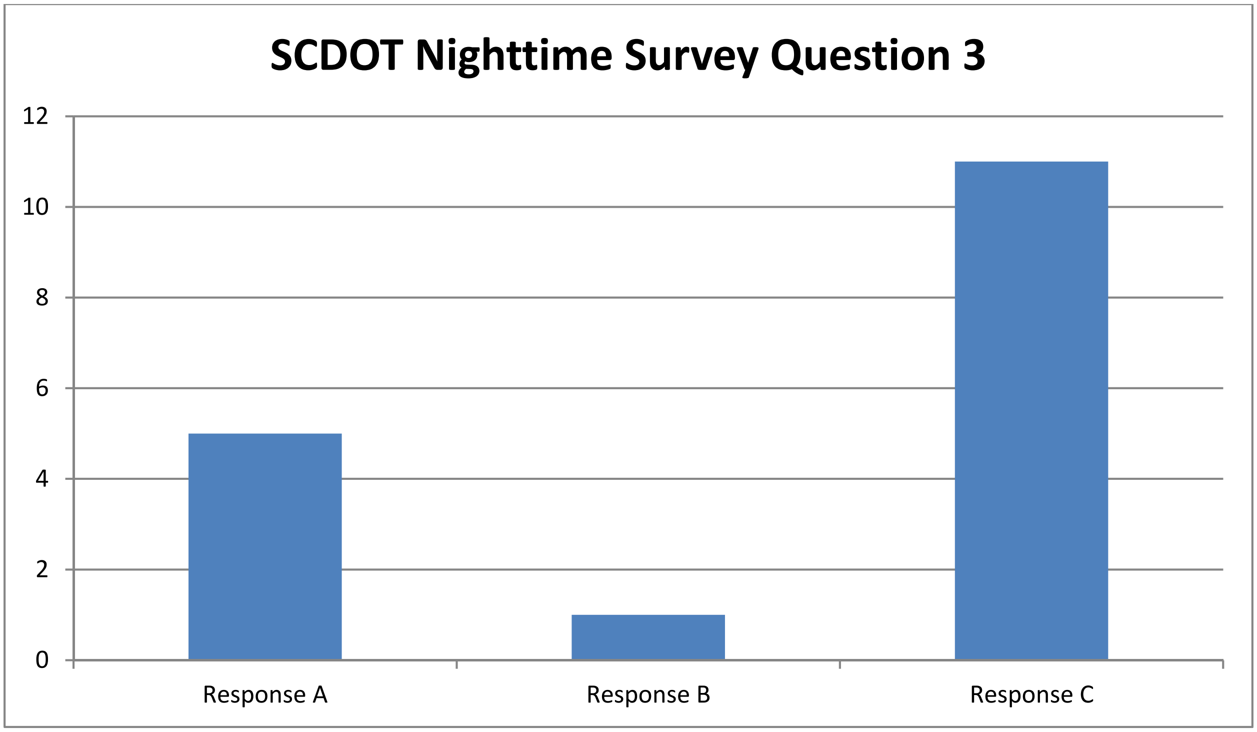


Figure 11-3: Results of SCDOT Nighttime Survey Question 3

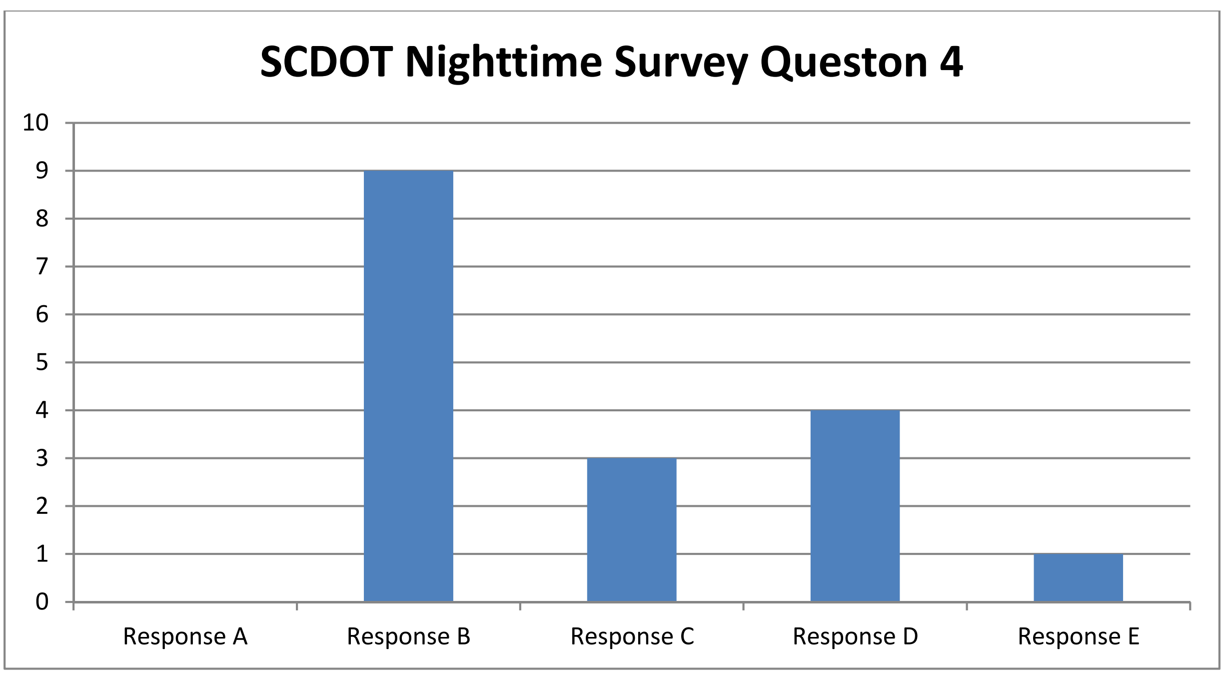


Figure 11-4: Results of SCDOT Nighttime Survey Question 4

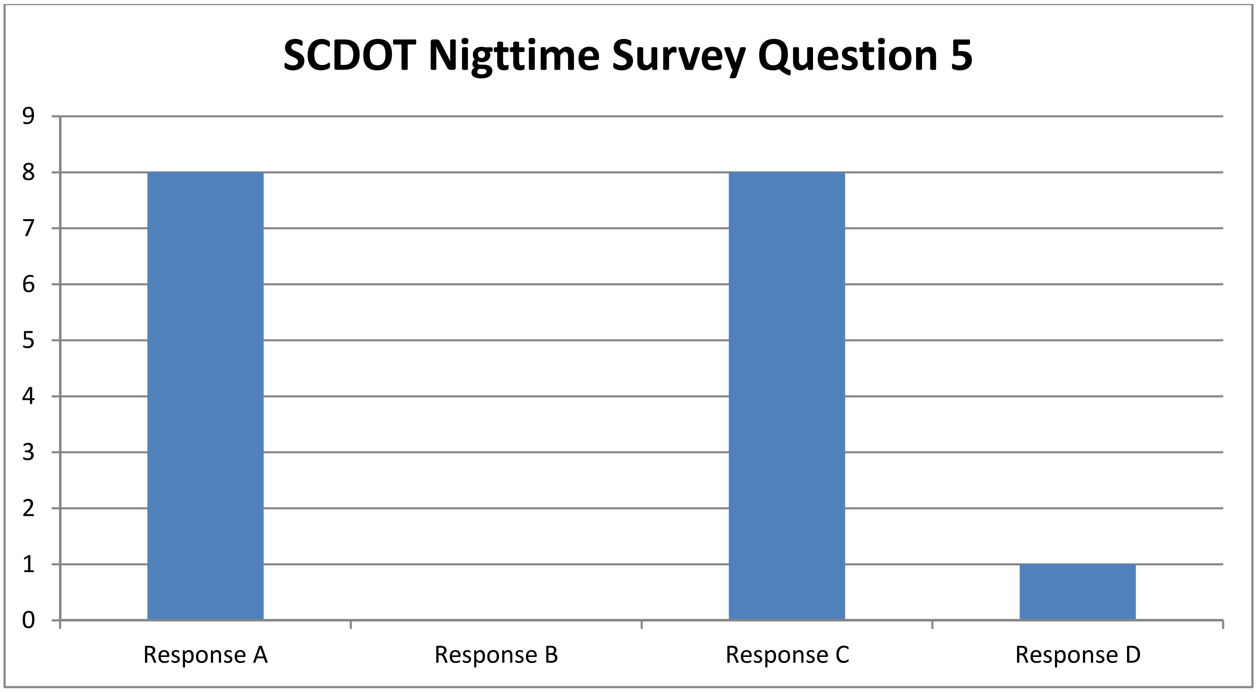


Figure 11-5: Results of SCDOT Nighttime Survey Question 5

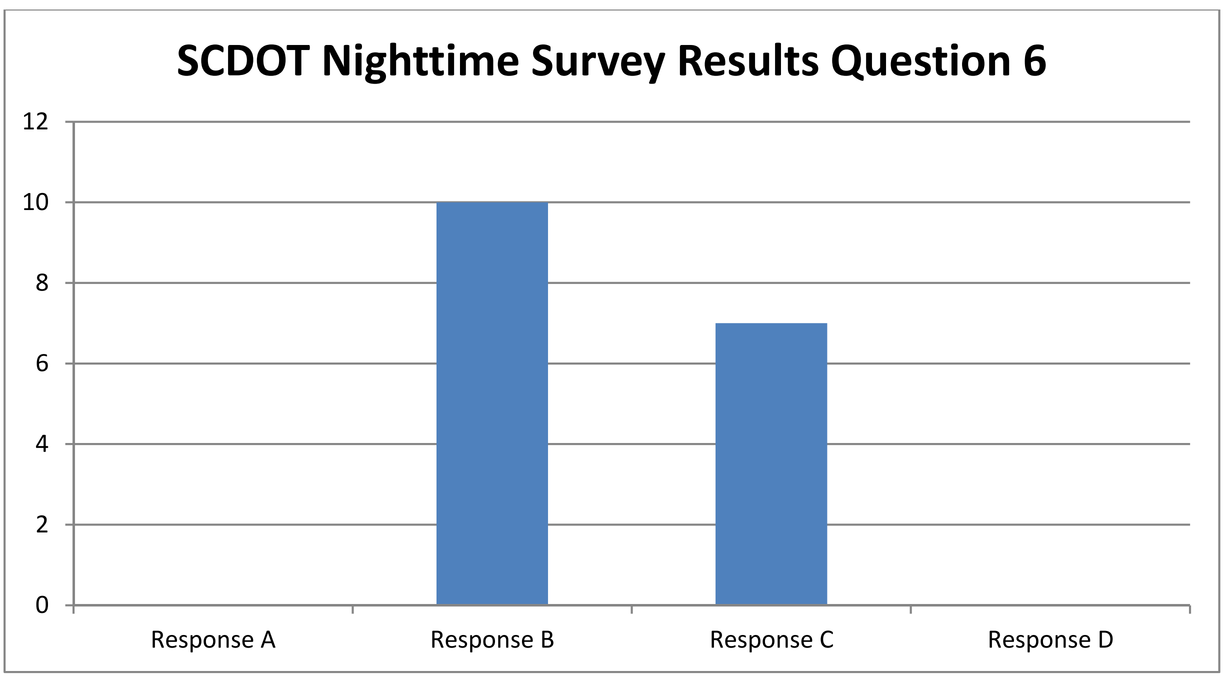


Figure 11-6: Results of SCDOT Nighttime Survey Question 6

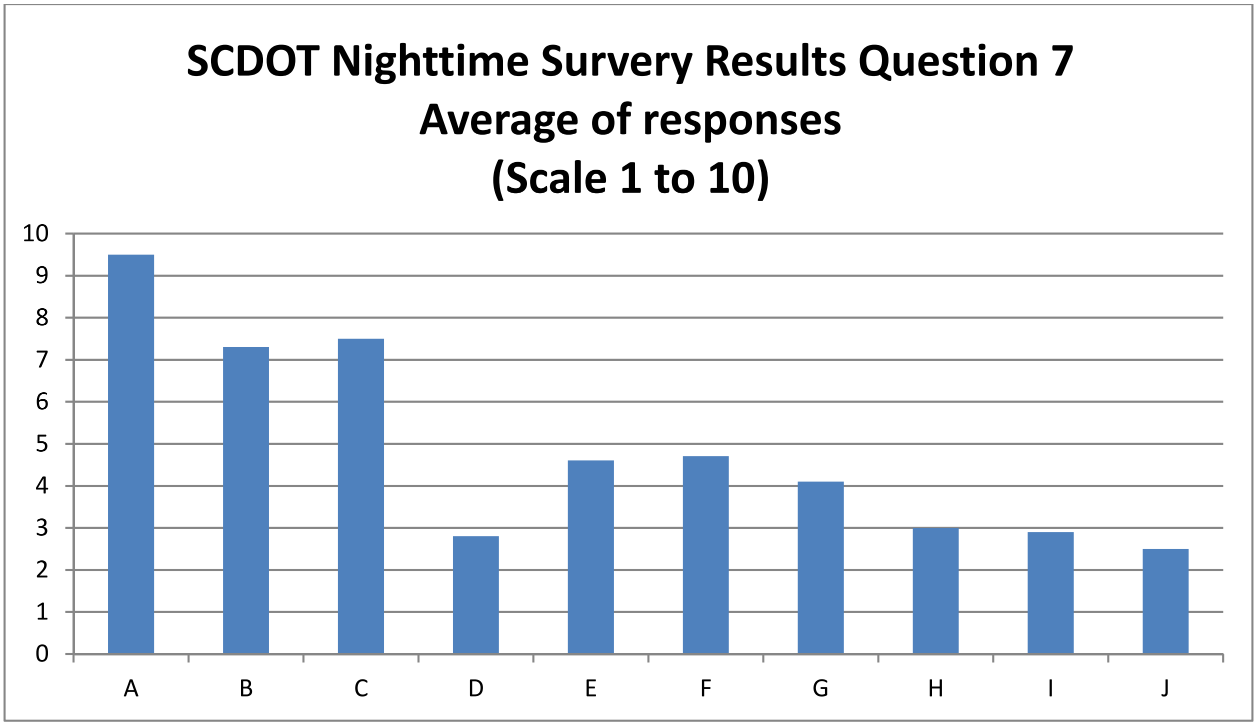


Figure 11-7: Results of SCDOT Nighttime Survey Question 7

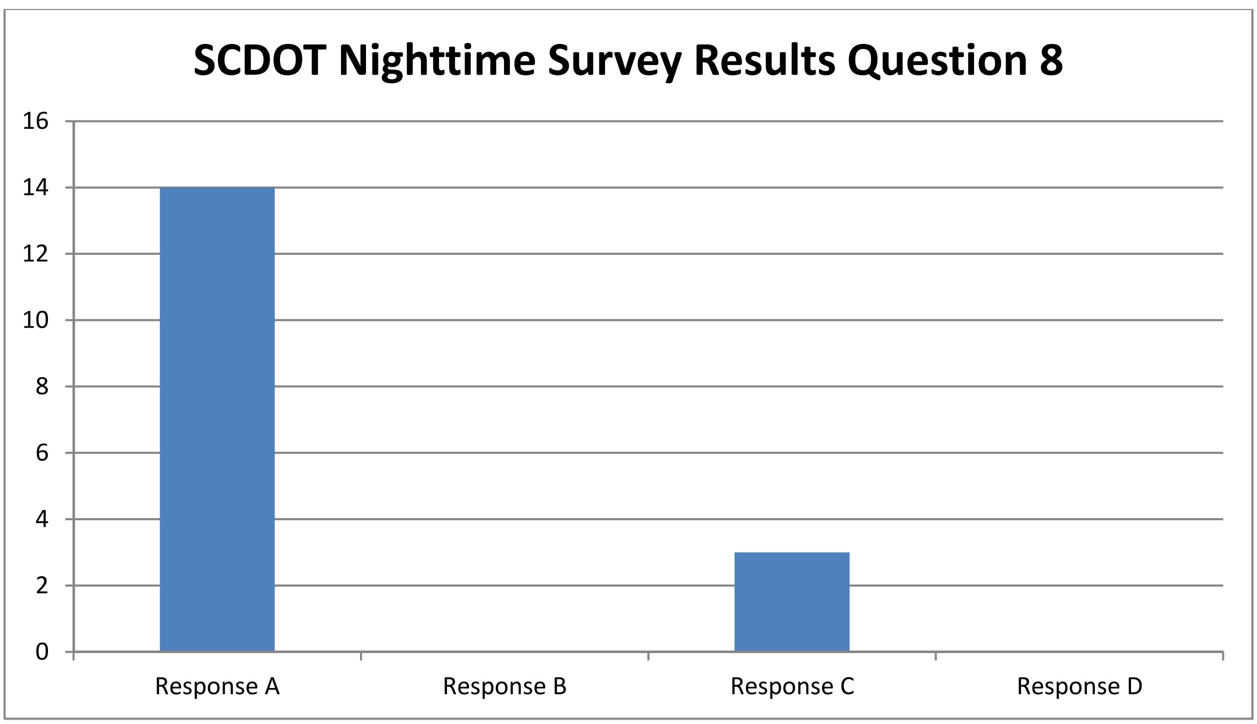


Figure 11-8: Results of SCDOT Nighttime Survey Question 8

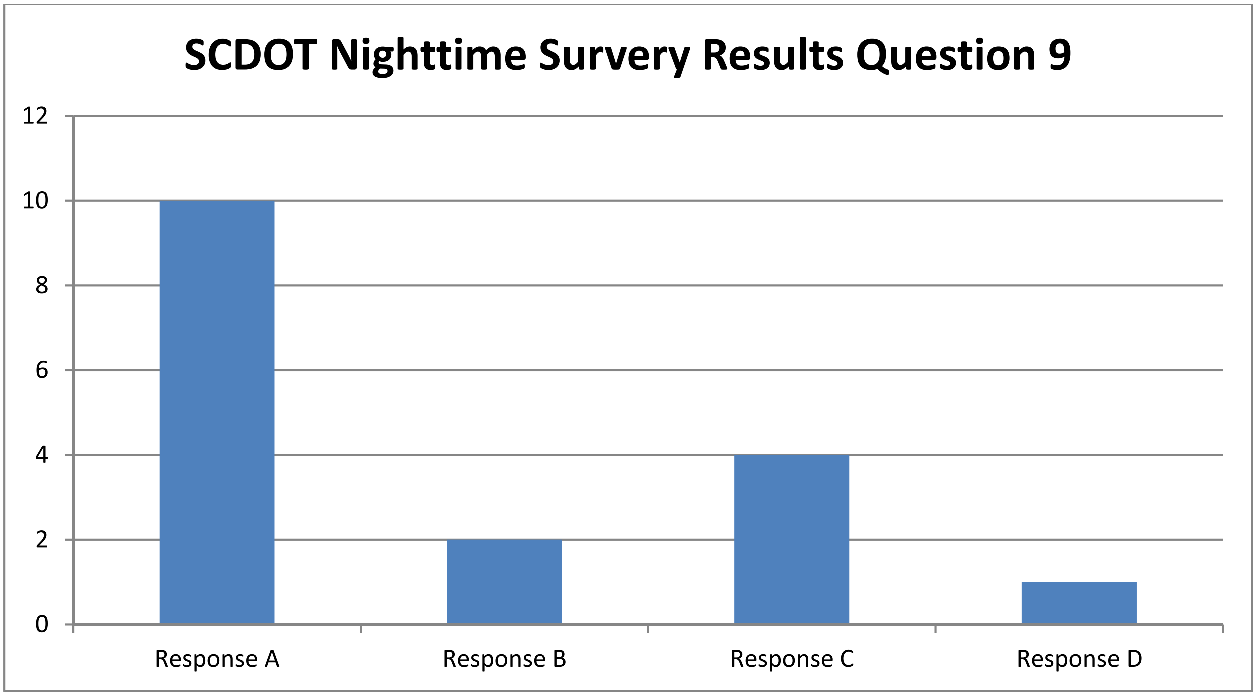


Figure 11-9: Results of SCDOT Nighttime Survey Question 9

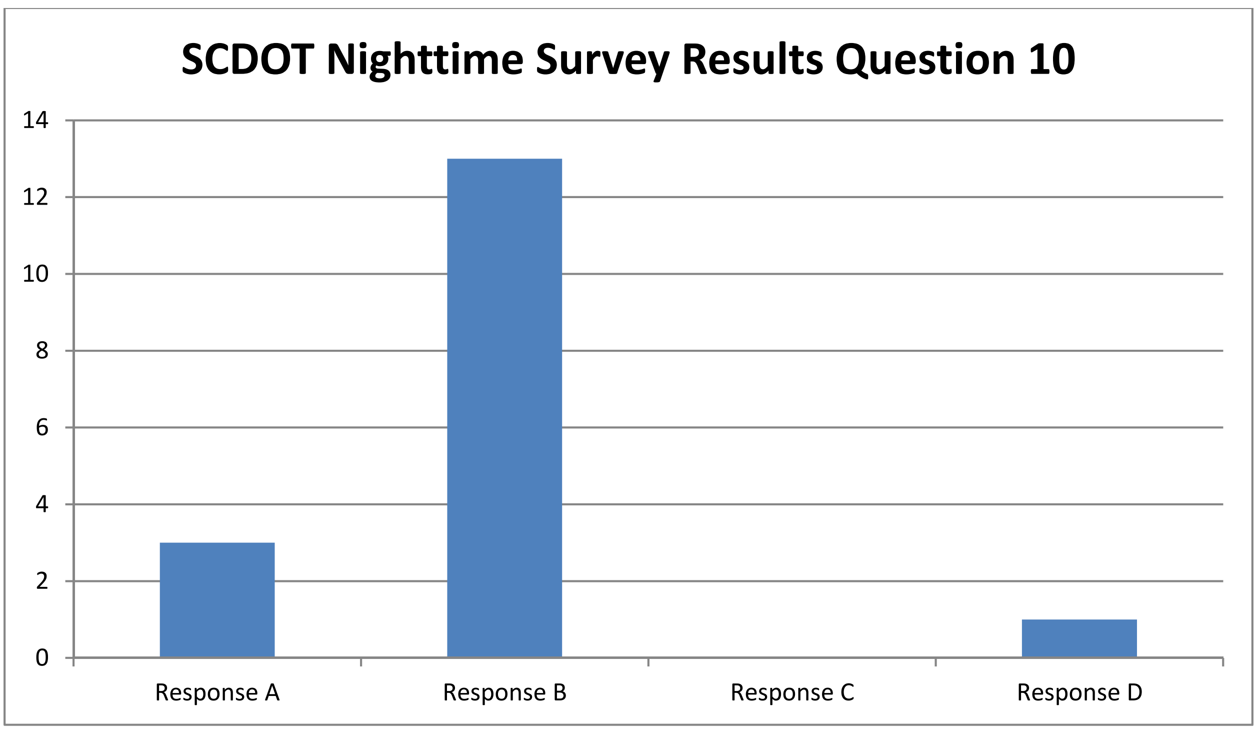


Figure 11-10: Results of SCDOT Nighttime Survey Question 10

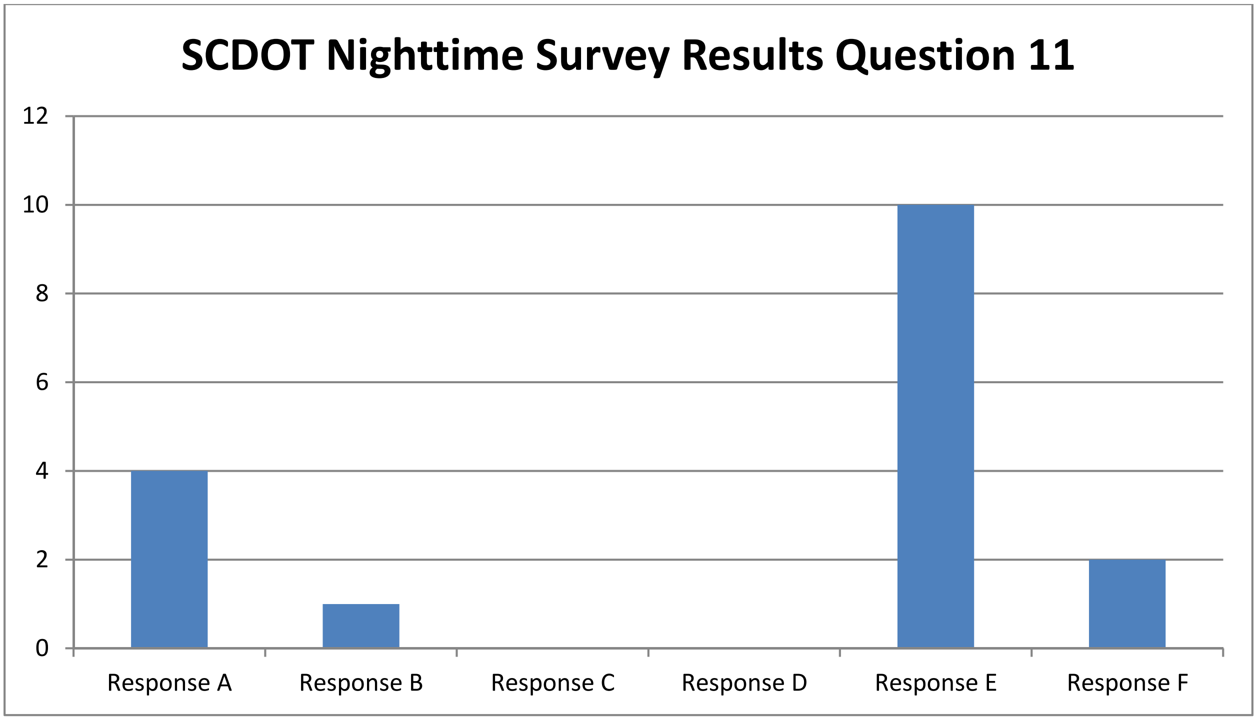


Figure 11-11: Results of SCDOT Nighttime Survey Question 11

12 Appendix F

12.1 Results of the State DOTs Nighttime Paving Survey

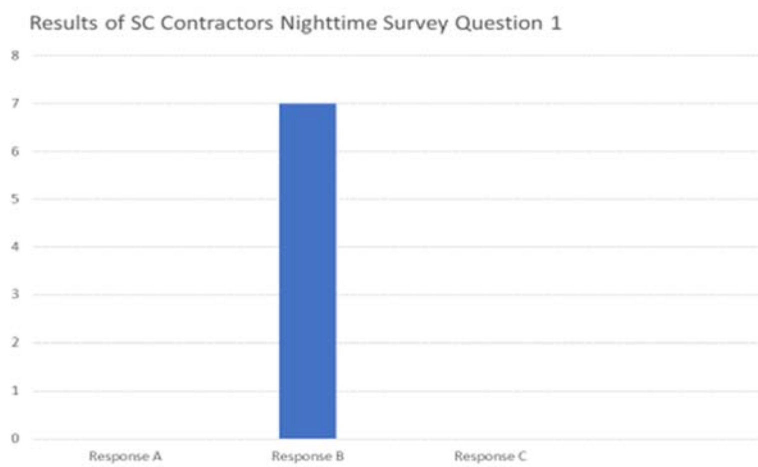


Figure 12-1: Results of SC Contractor's Nighttime Survey Question 1

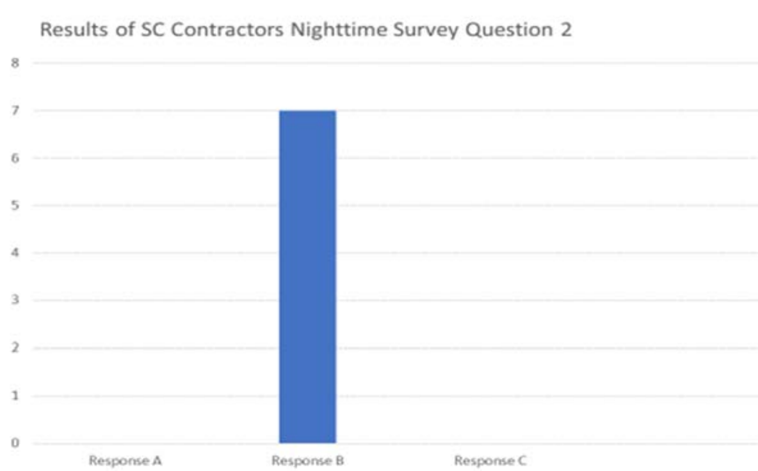


Figure 12-2: Results of SC Contractor's Nighttime Survey Question 2

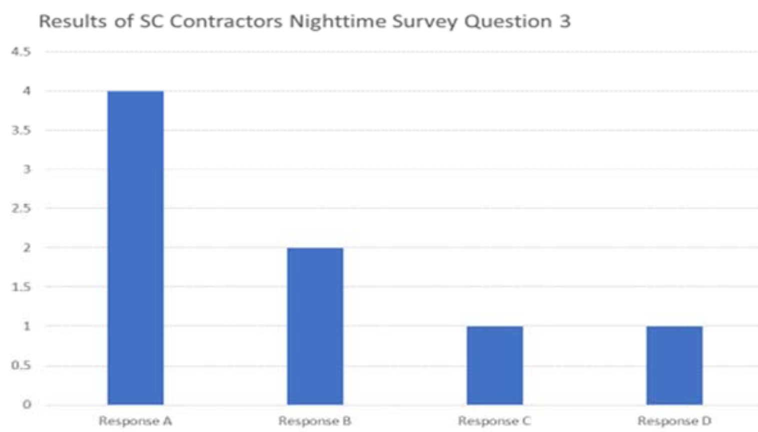


Figure 12-3: Results of SC Contractor's Nighttime Survey Question 3

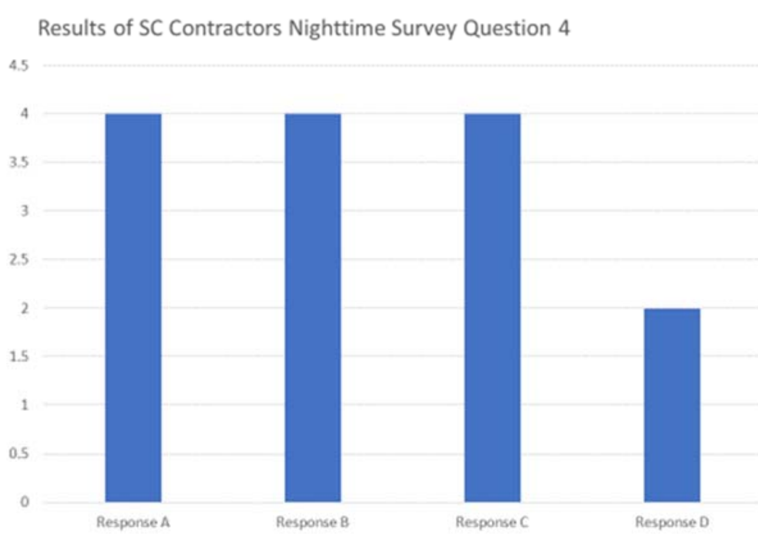


Figure 12-4: Results of SC Contractor's Nighttime Survey Question 4

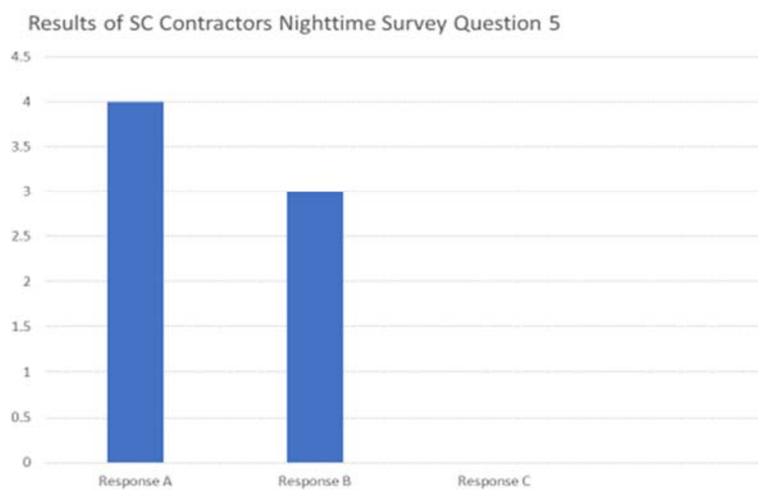


Figure 12-5: Results of SC Contractor's Nighttime Survey Question 5

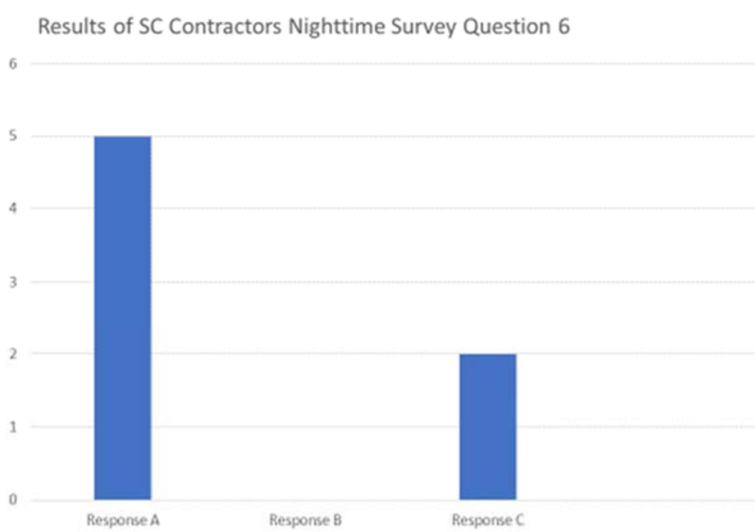


Figure 12-6: Results of SC Contractor's Nighttime Survey Question 6

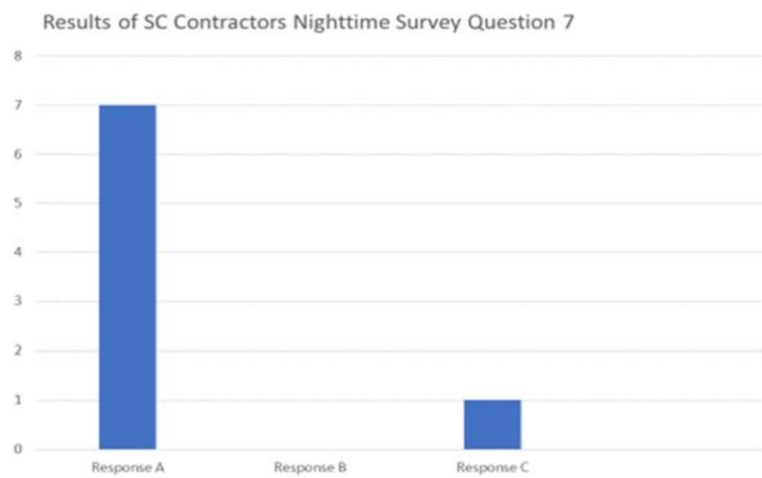


Figure 12-7: Results of SC Contractor's Nighttime Survey Question 7

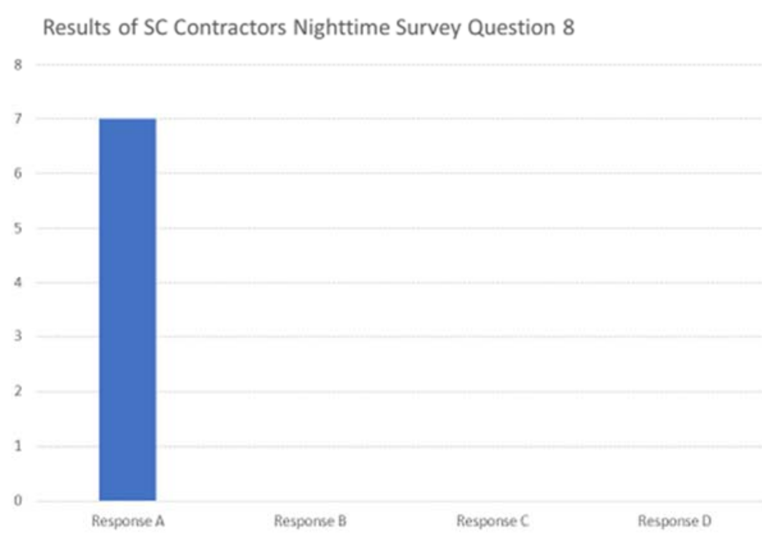


Figure 12-8: Results of SC Contractor's Nighttime Survey Question 8

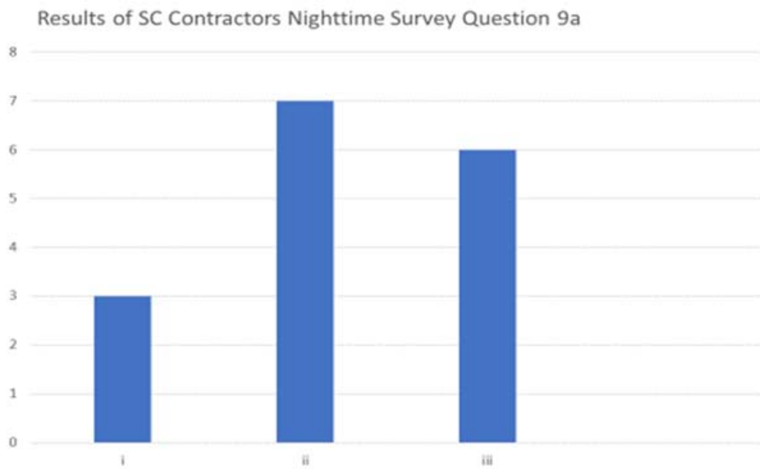


Figure 12-9: Results of SC Contractor’s Nighttime Survey Question 9a

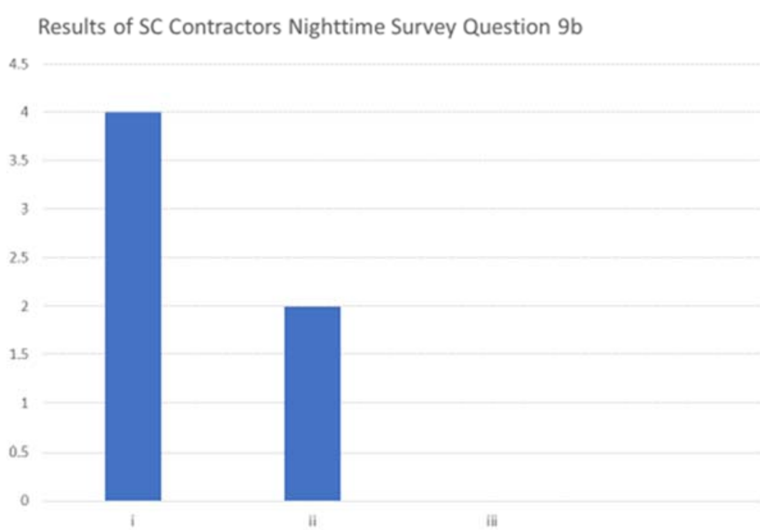


Figure 12-10: Results of SC Contractor’s Nighttime Survey Question 9b

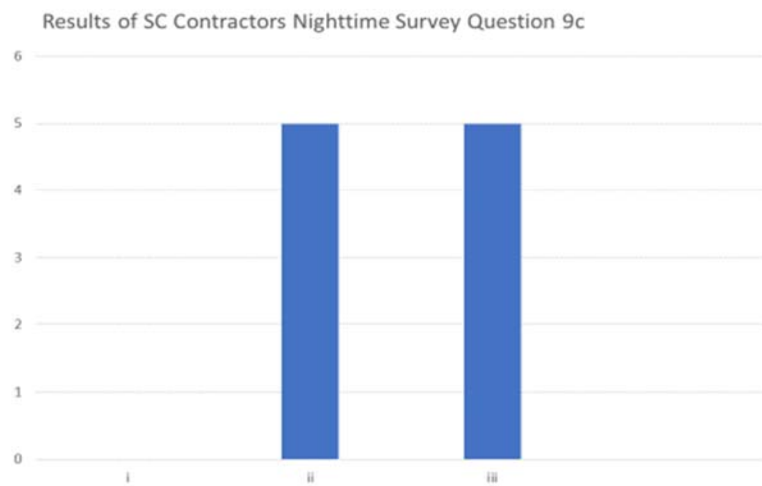


Figure 12-11: Results of SC Contractor's Nighttime Survey Question 9c

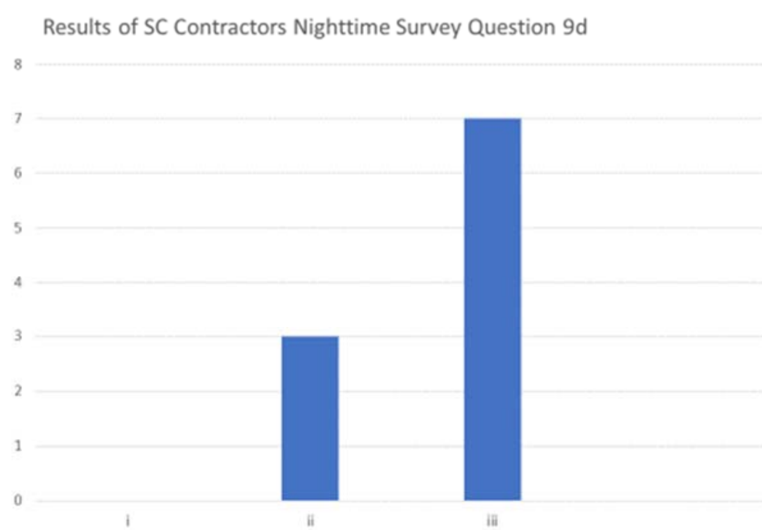


Figure 12-12: Results of SC Contractor's Nighttime Survey Question 9d

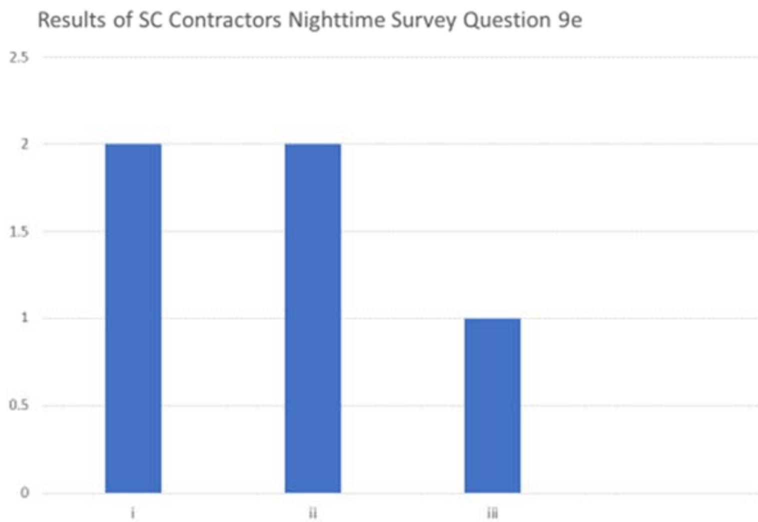


Figure 12-13: Results of SC Contractor's Nighttime Survey Question 9e

13 References: Cited or Reviewed

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